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Editor's Corner

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The year 2017 is ending with a flourish of activity for NASA Earth Science.

I am very pleased to report the successful launch of the first Joint Polar Satellite System mission (JPSS-1) that lifted off from Vandenberg Air Force Base in California at 1:47 AM Pacific Standard Time on November 18, 2017, onboard a Delta-II rocket. JPSS-1, the first of four planned spacecraft in the program, continues almost all of the observations that the preparatory Suomi NPP mission (launched in 2011) collects, and is the successor to the current-generation Polar Operational Environmental Satellite (POES) series. The satellite's payload includes the Visible-Infrared Imaging Radiometer Suite (VIIRS), Crosstrack Infrared Sounder (CrIS), Advanced Technology Microwave Sounder (ATMS, see first light image below), Ozone Mapping Profiler Suite (OMPS), and Clouds and the Earth's Radiant Energy System (CERES) Flight Model 6 (FM6). The satellite became NOAA-20 on successfully reaching orbit.

NASA also launched four CubeSats along with JPSS-1, including the Microwave Radiometer Technology Acceleration (MiRaTA)—developed by a team from Massachusetts Institute of Technology (**Kerri Cahoy**, Principal Investigator). MiRaTA, part of NASA's In-Space Validation of Earth Science Technologies (InVEST) program, will measure temperature, water vapor, and cloud ice in the atmosphere for severe weather monitoring and the study of cyclone structure.[1]

[1] To learn more about MiRaTA and the other CubeSats that launched with JPSS-1, visit *https://www.nasa.gov/feature/elana-xiv-cubesat-launch-on-jpss-1-mission*.

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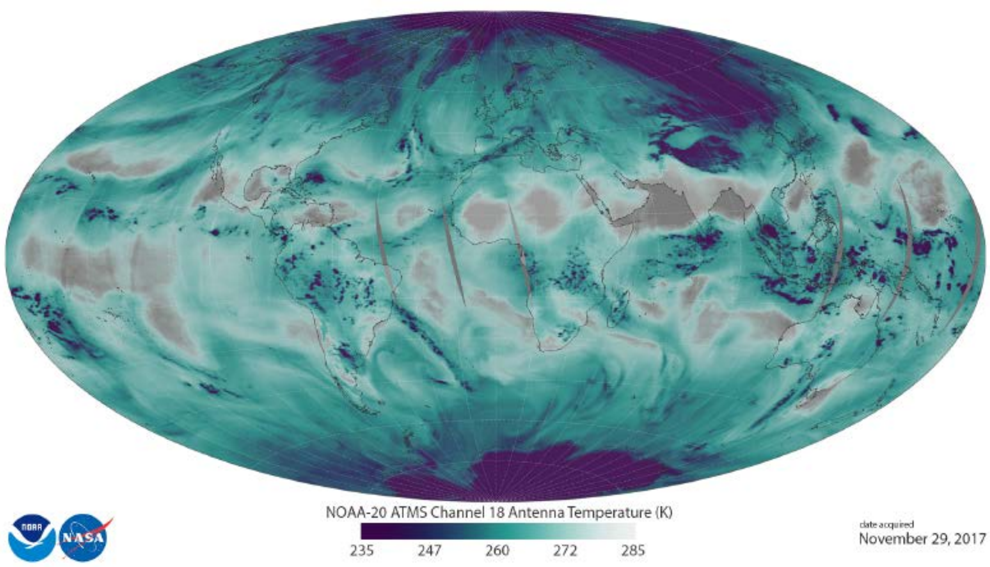

Eleven days after JPSS-1 launched into Earth orbit, the satellite, now known as NOAA-20, sent back its first Advanced Technology Microwave Sounder (ATMS) science data as part of a series of instrument startups and checkouts that will take place before the satellite goes into full operational mode. The image shows an ATMS channel antenna temperature that is associated with the location and abundance of water vapor in the lower atmosphere, from the surface of the Earth to 5 km (~3 mi) altitude. Water vapor distribution in space and time is a critical measurement for improving global weather forecasts. **Image credit:** NOAA, NASA

In This Issue

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

In addition, the Total and Spectral Solar Irradiance Sensor (TSIS-1) launched from KSC onboard a SpaceX Falcon 9 at 10:35 AM Eastern Standard Time on December 15, 2017—just as this issue of *The Earth Observer* goes to press. As of this writing, the Dragon capsule is on its way to the International Space Station (ISS) where the TSIS-1 total and spectral solar irradiance instruments will be hosted.

Congratulations to all these mission and instrument teams! I look forward to providing updates in future editorials.

JPSS-1's polar orbit observations complement those of the GOES-16 satellite that launched into a geosynchronous orbit in November 2016. Like JPSS-1, GOES-16 is the first of four planned spacecraft in the "GOES-R" series. GOES-16 is currently drifting to the GOES-East operational location of 75.2° west longitude and is expected to be in position by December 20, 2017. Meanwhile, GOES-S, the second satellite in the series, is now at KSC and planning for a March launch. Please turn to page 4 to learn more about GOES-16 as it celebrates a year in orbit.

As new missions begin, inevitably others come to an end. After more than 15 years in orbit, the joint NASA–DLR Gravity Recovery and Climate Experiment (GRACE) has ended. The mission consisted of two identical satellites (GRACE-1 and GRACE-2) following each other in orbit and using a microwave ranging system to measure micron-scale variations in the 137-mi (220-km) distance between the spacecraft to infer changes in Earth's gravitational field and related water storage changes.

On September 3, 2017, one of 20 battery cells on GRACE-2 ceased operating. This was the eighth such battery cell loss on GRACE-2 since launch in 2002—on what was designed to be a five-year mission. The following day, contact was lost with GRACE-2. However, the multi-agency GRACE mission operations team[2] restored communication on September 8. Subsequent analyses revealed that the battery cell lost on September 3 had recovered its full voltage, and that GRACE-2 had essentially hibernated during the period of lost contact—consuming no fuel. Following an assessment of the satellite's overall health, the team uplinked commands to place GRACE-2 in a passive state and initiated operational procedures in an attempt to extend the mission through its next science operations phase (mid-October to early November). The idea was that, GRACE-2 would be in full sun at that time, so it would not need to use its batteries.

However, on October 12, it became apparent that the battery cell that failed in September was no longer functional and there was no longer sufficient power stored in the remaining batteries to reliably operate the science

[2] Includes JPL, DLR (in Oberpfaffenhofen, Germany), and GFZ.

instruments and transmitter. In accordance with existing directives from the mission's Joint Steering Group, comprised of all U.S./German mission partners, and after a mission health assessment by the mission operations team, a decision was made to decommission GRACE-2, expend its remaining fuel, and place it in a passivated state in preparation for de-orbiting. Since both satellites are required to make the science measurements, the loss of GRACE-2 means GRACE will no longer be able to continue its dual satellite science mission.

While this is disappointing, the good news is that the successor mission, GRACE Follow-On (GRACE-FO), is scheduled to launch early in 2018 to continue GRACE's legacy. GRACE-FO will also test a new intersatellite instrument called the Laser Ranging Interferometer (LRI), developed by a German/American joint collaboration for use in future generations of gravitational research satellites. GRACE-FO arrived at Vandenberg Air Force Base on December 12.

After 33 months of operation onboard the ISS, the Cloud-Aerosol Transport System (CATS) has ended on-orbit operations. CATS provided measurements of the vertical structure of clouds and aerosols. With the precessing orbit of the ISS, CATS was able to observe the same locations at different times of day, allowing scientists a unique capability for studying diurnal changes in cloud and aerosol properties from space. The instrument is also the first space-based lidar to provide cloud and aerosol data to users in near-real-time (less than six hours).

The project was also unique because of its quick construction (less than two years), low-budget, and placement on the ISS. The CATS mission has helped evolve and streamline the process for placing other NASA payloads on the ISS. I congratulate the CATS team as this very successful mission comes to an end.

While the CloudSat misson is not ending, it is making preparations to exit the Afternoon "A-Train" Constellation, which it has been part of since its launch in 2006. In early June, one of four reaction wheels on CloudSat began to show significantly increased friction, and before mid-July the wheel was declared to have failed. While CloudSat can collect science data and continue to operate on the three remaining reaction wheels, the concern was that if another wheel failed, the spacecraft might not be able to safely control itself during future maneuvers and thereby potentially endanger other A-Train assets. The CloudSat mission team has been working on an alternative thruster-only maneuvering capability as a contingency plan should another reaction be lost. While progress has been made, it was decided that CloudSat will maneuver to a safe-exit orbit (lower altitude) from the A-Train as soon as feasible in the interest of constellation safety. Options for a final orbit are still being developed.

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

CloudSat has operated far longer than all expectations, providing outstanding science return. This is a testament to an extraordinary mission team that, notably, kept CloudSat operating despite battery anomalies that required modified power operations (daylight only operations) starting in 2011. *The Earth Observer* team will continue to monitor developments with CloudSat and keep our readers informed as events warrant.

This issue also contains an article that focuses on the GLOBE Program and their efforts to broaden their reach through citizen science efforts, using the GLOBE Observer app. Through citizen science, science-interested volunteers all around the world can participate in the process of gathering and analyzing scientific data. While the idea is not new, recent advances in computing technologies have made it more practical to implement. GLOBE Observer grew out of the GLOBE Program, an international science and education program established in 1994 that provides students and the public worldwide with the opportunity to participate in data collection and the scientific process, and contribute meaningfully to our understanding of the Earth system and global environment. The GLOBE Observer app expands GLOBE to nonstudent audiences, simplifying data collection by removing equipment requirements and simplifying the steps for data collection for users. The GLOBE Observer app works on iPhones and Android devices and is available for free in the App Store and Google Play. Turn to page 15 to learn more about these efforts and how you too can become a GLOBE citizen scientist.

As another calendar year draws to a close, I continue to be proud of the ways in which this newsletter and other outreach activities performed by the agency (e.g., the recently completed highly successful NASA Science Mission Directorate exhibit at the AGU Fall Meeting) allow the agency to put its best foot forward and showcase how NASA continues to extend scientific knowledge for the benefit of the nation and the planet. None of this is possible without the continued support and interest of *you*—our readers, contributors, and outreach participants. On behalf of *The Earth Observer* staff and the Earth Science Division, our sincere thanks to the many individuals who contributed to our success over the past year, and best wishes to all in the year ahead. ■

Note: List of undefined acronyms from the *Editor's Corner* and the *Table of Contents* can be found on **page 55**.

feature article

GOES-16: The First in a New Generation of Geostationary Satellites

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The Geostationary Operational Environmental Satellite (GOES) system provides data for weather forecasting; monitoring severe storms, hurricanes, fires, volcanic ash, and lightning; space weather characterization and forecasts; and meteorological research.

Introduction

The Geostationary Operational Environmental Satellite (GOES) system is the geostationary-orbit component of the National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS). It provides data for weather forecasting; monitoring severe storms, hurricanes, fires, volcanic ash, and lightning; characterizing and forecasting space weather; and meteorological research. The first GOES satellite, GOES-1, was launched in 1975, beginning the long, successful run of the GOES series (see **Figure 1** and **Table 1**).[1] GOES-R is the latest NOAA–NASA GOES mission; it launched on November 19, 2016, and was renamed to GOES-16 after launch and on-orbit checks were complete. **Figure 2** illustrates the geographical coverage and approximate orbital positions of the GOES satellites once GOES-16 attains operational status early in 2018. Spacecraft and ground-based elements of the system work together to provide a continuous stream of environmental data, used by (among others) the National Weather Service (NWS) and by national meteorological and hydrological services throughout the world, for weather monitoring and forecasting operations, and by the scientific community to better understand land, atmosphere, ocean, and climate interactions.

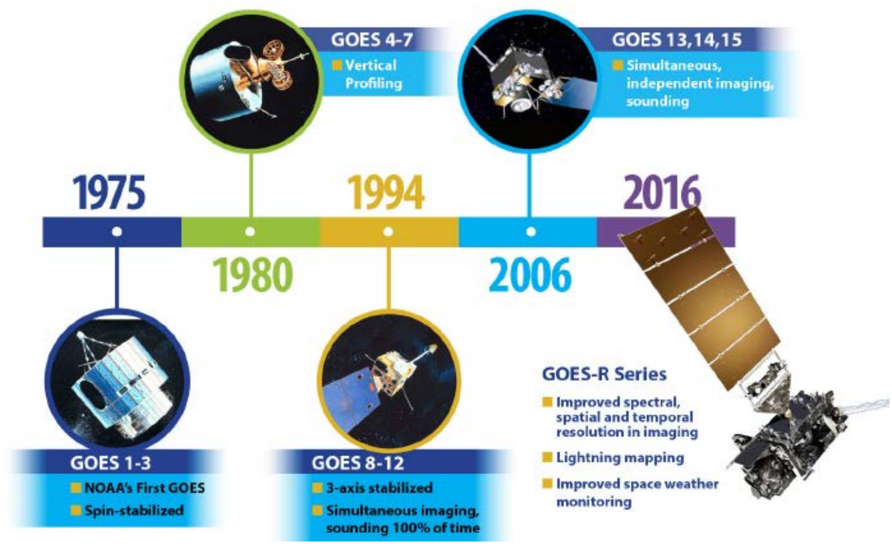

Figure 1. The GOES series has gone through evolutionary development with improvements in both the spacecraft and instruments. Further information on the series can be found at *http://www.goes-r.gov/mission/history.html*. **Image credit:** NOAA/NESDIS

Table 1. Name and launch date of each GOES mission.

Satellite Name[+]	Year Launched (*Scheduled*)
SMS*[*]*-Derived [1975-1979]	
GOES-A (1)	October 16, 1975
GOES-B (2)	June 16, 1977
GOES-C (3)	June 16, 1978
GOES First Generation [1980–1993]	
GOES-D (4)	September 9, 1980
GOES-E (5)	May 22, 1981
GOES-F (6)	April 28, 1983

continued on next page

[1] To learn about previous GOES missions, visit *https://www.nasa.gov/content/goes-overview/index.html*.

Table 1. Name and launch date of each GOES mission. (cont.)

Satellite Name+	Year Launched (*Scheduled*)
GOES-G	May 3, 1986
GOES-H (7)	February 26, 1987
GOES Second Generation [1994-2005]	
GOES-I (8)	April 13, 1994
GOES-J (9)	May 23, 1995
GOES-K (10)	April 25, 1997
GOES-L (11)	May 3, 2000
GOES-M (12)	July 23, 2001
GOES Third Generation [2006-2015]	
GOES-N (13)	May 24, 2006
GOES-O (14)	June 27, 2009
GOES-P (15)	March 4, 2010
GOES-Q	N/A
GOES Fourth Generation [a.k.a., GOES-R Series] [2016–TBD]	
GOES-R (16)	November 19, 2016
GOES-S	*2018*
GOES-T	*2019*
GOES-U	*2025*

Table Notes:

+ Satellites in the GOES series receive a number once they are successfully launched and complete on-orbit checkout. Thus, no number was assigned to GOES-G (launch failure) or GOES-Q (proposed, but never built).

* SMS stands for Synchronous Meteorological Satellite, two NASA-developed, spin-stabilized, geosynchronous satellites that were launched in 1974 and 1975, respectively.

GOES-16 is the first in the GOES-R series, which includes GOES-R, -S, -T, and -U, that will launch between now and 2025, ushering in a new era of geosynchronous observing capabilities.

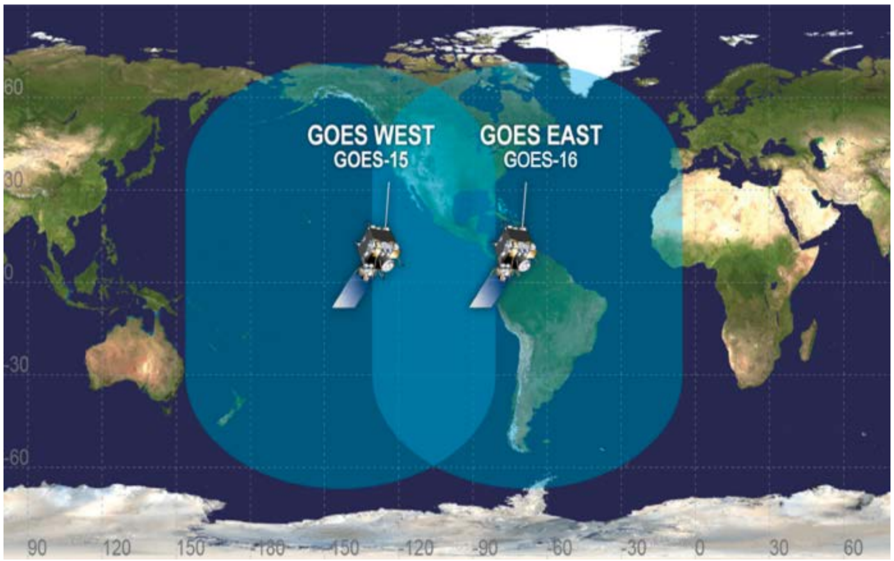

Figure 2. The GOES satellites operate from two primary locations: GOES East (GOES-16) is located at 75° W longitude and provides most of the U.S. weather information, and GOES West (GOES-15) is located at 135° W longitude. The observing latitude range for both satellites is between 68° N and S. Once GOES-16 becomes operational in early in 2018, NOAA will store on-orbit backup GOES satellites at 60° W longitude (GOES-13) and at 105° W longitude (GOES-14). They can be placed into service in the event of an anomaly or failure of GOES East or GOES West. **Image credit**: Adapted from NOAA/NESDIS

To support marine and aviation route activities, NOAA's weather-forecasting responsibilities cover the area from Guam to the West coast of Africa. As part of NOAA's fleet of operational satellites, the GOES satellites are positioned to view the east coast and Atlantic Ocean (GOES-East), and the west coast of the U.S. and the Pacific Ocean (GOES-West)—positions depicted in Figure 2.

GOES-16 is the first in the GOES-R series, which includes GOES-R, -S, -T, and -U, that will launch between now and 2025, ushering in a new era of geosynchronous observing capabilities. This article, published approximately one year after the launch of GOES-16, is intended to introduce the new series. It will discuss the GOES-16

To meet the need for extremely stable Earth and solar pointing; high-speed, near-error-free instrument data transmission; and a very quiet electromagnetic background, the spacecraft is stabilized in all three-axes with high accuracy, necessary to allow continuous high-quality instrument measurements and data communications with Earth.

satellite's improvements, including spacecraft design, its manifest of advanced instruments, resultant data products, and anticipated societal benefits. The article will summarize the contributions to the GOES series successes by way of partnerships with NASA and collaborations with the broader international community on environmental observations (see *The GOES Series: Success Through an Interagency Partnership and via International Collaboration* on page 7), discuss how GOES-16 data products are being validated and distributed, and provide examples of how GOES-16 data have already been put to use.

An overview of the entire GOES-16 mission appears at *http://www.goes-r.gov*. The site includes information ranging from technical capabilities of the instruments and spacecraft to data products and user training.

The GOES-R Series Spacecraft

The GOES-R series design builds on requirements and technology of the previous missions. The first of these, GOES-16 (shown in **Figure 3**), consists of the spacecraft bus, the environmental sensing instruments, and a set of communications payloads.[2] To meet the need for extremely stable Earth and solar pointing; high-speed, near-error-free instrument data transmission; and a very quiet electromagnetic background, the spacecraft is stabilized in all three axes with high accuracy, necessary to allow continuous high-quality instrument measurements and data communications with Earth.

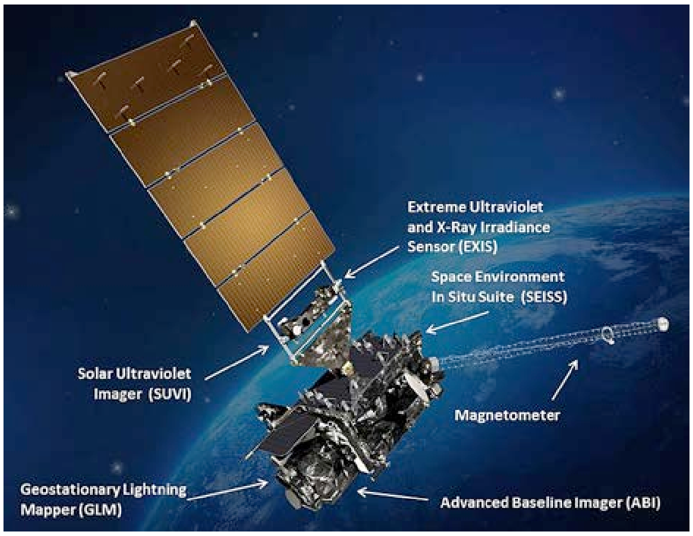

Figure 3. Location of the instruments on the GOES-R series of satellites. **Image credit:** Lockheed Martin

To meet mission requirements, the GOES-16 design employs several technological innovations, including low-thrust rocket engines that allow instrument observations to continue during maneuvers, and the first civilian use of Global Positioning System-based orbit determination for geostationary orbit. Each satellite in the GOES-R series is designed for 10 years of operations and 5 years of in-orbit storage.

GOES-16 Instruments and Their Data Products

As described earlier, each GOES series builds on the technology of the previous series. The GOES-16 and the three follow-on GOES-R missions carry six, high-performance instruments, each providing multiple data products that meet the mission data requirements for a range of environmental science parameters with high accuracy and spatial and temporal resolution.

There are two Earth-viewing instruments: the Advanced Baseline Imager (ABI) and Geostationary Lightning Mapper (GLM); two solar-viewing instruments: the Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS) and Solar Ultraviolet Imager (SUVI); and two space-facing instruments: the Magnetometer (MAG) and Space Environment In Situ Suite (SEISS). Each of these are described here. A list of data products required for each science parameter, sorted by instrument appears in **Table 2** on page 9.

[2] In addition to supporting environmental sensing payloads, GOES-R also carries a set of Ultra High Frequency (S-, L-, and X-band) transponders that provide communications relay services and GOES mission data transmission. The suite consists of the Data Collection System (DCS), the High Rate Information Transmission/Emergency Managers Weather Information Network (HRIT/EMWIN), GOES Rebroadcast (GRB), and the Search and Rescue Satellite-Aided Tracking (SARSAT) system.

The GOES Series: Success Through an Interagency Partnership and International Collaboration

NASA Partnership

The GOES partnership between NOAA and NASA is but one chapter in a long history of collaboration between the two organizations that goes well beyond the scope of this article.* The initial Basic Agreement between NOAA and NASA to work together on GOES, signed in 1975, established that NOAA would provide requirements and funding for the GOES Program, and that NASA would serve as NOAA's agent in procuring and overseeing development of the satellites. In 1998 NOAA and NASA updated the Basic Agreement, assigning to NASA's Goddard Space Flight Center (GSFC) the responsibility for procuring, developing, and testing GOES Program spacecraft and instruments, and with NOAA responsible for satellite operations, science algorithms, and ground processing.

The partners agreed that NOAA would manage the GOES-R Series Program (including GOES-16 and the future satellites) through an integrated NOAA–NASA office, staffed with personnel from both agencies. Using NOAA's requirements, NASA would then be responsible for acquiring and developing the platforms, including spacecraft and instrument testing, following NASA's Science Mission Directorate's rigorous flight program and project management processes. As part of this agreement, GSFC provides spacecraft launch services and then tests the satellite and instruments for the first 6–12 months in orbit before turning the mission over to NOAA's National Environmental Satellite, Data, and Information Service (NESDIS). NASA collaboration roles go further than providing engineering and acquisition services for GOES; the agency also provides scientific support by welcoming NOAA's scientists to participate in its Earth science research mission teams. The collaborative efforts include algorithm development, pre- and post-launch testing, and designing and implementing the calibration and validation program (usually called "cal/val"), discussed later in this article.

The collaboration is not limited to GOES, but includes NOAA's polar-orbiting operational satellites, where there is considerable overlap of mission activities. NASA's role in "Research to Operations,"** an effort that promotes the application of research space products to routine societal benefits, is a key component of the partnership.

International Collaborations

International collaboration is a high priority for NOAA to ensure that investments in satellite observations are interoperable and made available to the public, globally. To meet these goals, NOAA participates in the Committee for Earth Observing Satellites, Group on Earth Observations, World Meteorological Organization, and the Coordination Group for Meteorological Satellites (CGMS). The primary objectives of the CGMS include providing a forum for technical exchange on meteorological satellite systems; coordinating missions, including establishing complementary orbits, sensors, data formats, processing algorithms, and cal/val activities; and encouraging mutual backup arrangements.

As an example, the Japan Meteorological Agency (JMA) and NOAA have a mutual backup arrangement. The two agencies' new-generation satellites carry similar advanced imagers [i.e., the Advanced Baseline Imager (ABI) on the GOES-R series is similar to the JMA's Advanced Himawari Imager (AHI) on Himarawi-8 and -9.*** Along similar lines, the Advanced Meteorological Imager (AMI) on the Korean Meteorological Agency's (KMA) GEO-KOMPSAT 2A satellite is almost identical to ABI, except for a single band.

Another example is the NOAA and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)'s Long-Term Cooperation Agreement, signed in 2013, which builds on a 30-year partnership in geostationary, polar-orbiting, and ocean altimetry satellites that has resulted in cost-saving benefits and increased the robustness of both agencies' observing systems. Similar agreements are in place with China, Korea, France, Canada, India, Australia, and other European agencies.

*Another chapter of the story of NASA–NOAA collaboration was told in "Nimbus Celebrates 50 Years" article in the March-April 2015 issue of *The Earth Observer* [**Volume 27, Issue 2,** pp. 18-31—*https://eospso.gsfc.nasa.gov/earthobserver/mar-apr-2015*].

** The concept of "Research to Operations" has steadily evolved under the direction of NASA and NOAA, and has been extensively studied by the National Academy of Science. To learn more, visit *https://www.nap.edu/read/10658/chapter/4#13* or *https://www.nap.edu/read/10658/chapter/7*.

*** Animated images from the JMA's AHI on Himarawi-8, which is positioned over the Western Pacific, are available at *http://www.goes.noaa.gov/f_himawari-8.html*.

Earth-Oriented Instruments

Advanced Baseline Imager

The ABI is the primary instrument on the GOES-R series. It is used for a wide range of applications relating to severe weather, aviation, natural hazards, the atmosphere, ocean, cryosphere, and air quality. The instrument views Earth with 16 spectral bands across visible, near-infrared, and infrared channels. The instrument has two scan modes: The default mode takes a hemispheric image every 15 minutes; an image of the continental U.S. every five minutes; and two smaller, more-detailed images of areas where storm or high-impact environmental phenomena such as fires and volcanic eruptions might be present, every 30-60 seconds. Because of new technology, ABI has three times the number of wavelength channels, four times better spatial resolution, and scans five times faster than previous GOES imagers.

Geostationary Lightning Mapper

Because of new technology, ABI has three times the number of wavelength channels, four times better spatial resolution, and scans five times faster than previous GOES imagers.

The GLM is the first operational lightning mapper flown in geostationary orbit.[3] GLM continuously measures total lightning (in-cloud, cloud-to-cloud, and cloud-to-ground) activity continuously over the Americas and adjacent ocean regions, with near-uniform spatial resolution of approximately 10 km (~ 6 mi). The measurements include lightning frequency, location, areal extent, and the change in the flash rates, to identify intensifying storms. Trends in total lightning from GLM's measurements, combined with the imagery and weather radar, may allow forecasters to predict developing severe storms—and possibly tornadoes—much earlier than had heretofore been possible.

Sun-Oriented Instruments

Solar Ultraviolet Imager

The SUVI is the follow-on instrument to the Solar X-ray Imager (SXI) flown on previous GOES satellites; it monitors the sun in the extreme ultraviolet wavelength range, and is able to compile full solar disk images around the clock. The measurements characterize complex active regions of the sun, e.g., solar flares and eruptions of solar filaments. These solar phenomena impact near-Earth space weather, and generate geomagnetic storms that can disrupt power utilities, and communication and navigation systems. They also may cause radiation damage to commercial and government satellites.

Extreme Ultraviolet and X-ray Irradiance Sensor

The EXIS detects and monitors solar irradiance in the upper atmosphere and extends the wavelength range beyond earlier GOES satellites. The instrument monitors solar flares that can disrupt communications and degrade navigational accuracy, thereby affecting satellites, high-altitude airliners, and power grid performance. It also monitors solar variations that directly affect satellite tracking and ionospheric changes that impact communications and navigation operations. The NOAA Space Weather Prediction Center (SWPC) relies on the products from the EXIS to issue warnings of potential radio blackouts.

Space-Oriented Instruments

Magnetometer

The MAG provides measurements of the intensity and the vector (i.e., the three directional components) of space magnetic fields, which control the charged-particle dynamics in the outer regions of the Earth's upper atmosphere. These particles can be

[3] A Lightning Imaging Sensor (LIS) flew on the Tropical Rainfall Measuring Mission (TRMM) and another currently flies on the International Space Station (ISS). In both cases, the instrument is located in inclined low-Earth orbits and thus unable to monitor lightning continuously over a given location. From its vantage point in geosynchronous orbit, GLM can make continuous observations, and has a 7.7-MBps data rate, which is 1000 times greater than that of the LIS instruments.

dangerous to spacecraft and humans during spaceflight. These measurements are also important for providing alerts and warnings to many customers, (e.g., satellite operators and power utilities) of impending geomagnetic storms, with possible deleterious consequences to their respective technologies and applications. A deployable boom is used to distance the magnetometers from the magnetic signature of the spacecraft.

Space Environment In Situ Suite

The SEISS, new for the GOES-R series, is comprised of four sensors that monitor proton, electron, and heavy ion fluxes in the magnetosphere to provide a complete picture of the energetic particles in the vicinity of the spacecraft, originating from the sun and cosmic rays. These measurements tell spacecraft operators and scientists the electrical charge conditions being experienced by the spacecraft. Discharge arcs can cause serious and permanent damage to spacecraft hardware, thereby affecting spacecraft navigation and instrument operations. SEISS data will also support the SWPC's solar radiation storm warnings.

The Space Environment In Situ Suite (SEISS), new for the GOES-R series, is comprised of four sensors that monitor proton, electron, and heavy ion fluxes in the magnetosphere to provide a complete picture of the energetic particles in the vicinity of the spacecraft originating from the sun and cosmic rays.

Table 2. Science Parameters, Instruments, and Data Products

Science Parameter	Instrument	Data Products
Atmosphere	ABI	Moisture - Vertical Profile Temperature - Vertical Profile Winds - Troposphere
Clouds, Precipitation, and Storms	ABI	Cloud Mask Cloud Properties (amount, height, temperature, optical properties, phase) Low Clouds and Fog Hurricane Intensity Estimation Rainfall Rate Total Precipitable Water
Composition	ABI	Aerosol Optical Depth (smoke and dust) Volcanic Ash Detection and Height Total Ozone
Radiation	ABI	Total Shortwave Radiation Exiting the Earth Atmosphere Total Shortwave Radiation Reaching the Earth's Surface
Land	ABI	Fire/Hot Spot Detection and Characterization Surface Temperature
Snow and Ice	ABI	Areal Extent
Sea-Surface	ABI	Temperature
Lightning	GLM	Flash Rate, Areal Extent (for storm intensity)
Space Weather	SEISS SEISS SEISS SUVI EXIS MAG	Energetic Heavy Ions Magnetospheric Low and High Energy Particles Solar and Galactic Protons Solar Flux: Extreme Ultraviolet (UV) and X-Ray Irradiances Solar Extreme UV Imagery Geomagnetic Field

The instruments on the GOES-R series are providing images with increased spatial resolution and more-frequent coverage for more-accurate forecasts, real-time mapping of lightning activity, and improved monitoring of solar activity and the space environment. After demonstrating its capabilities during the past year's check-out period, the satellite will become operational in January 2018 as GOES East.

Calibration and Validation

As in any new space mission, cal/val of GOES data products are critical and essential components to the success of its mission. The GOES cal/val program was designed to provide product performance information and data that allow an assessment of the degree to which GOES-16 products actually meet their specifications and users' requirements. Although the GOES-R algorithms went through a rigorous review, the validation campaign, described below, was put into place to determine if algorithm updates are necessary after they are tested with actual observations and compared with independent observations.

The independent cal/val data are being obtained from several sources, including ground and sea observations, coincident operational and research satellite data, and from a dedicated aircraft campaign.[4] The ABI atmospheric profile (temperature and moisture) data are being compared to similar data collected by balloon soundings and meteorological station networks. Other ABI data products (e.g., cloud, aerosol, land, and ocean characteristics) are being compared to data from NASA research satellites such as those in the Afternoon Constellation (A-Train)[5] and operational polar-orbiting satellites, such as NOAA's Suomi National Polar-orbiting Partnership (NPP) and the U.S. Geological Survey's Landsat satellites. Several EUMETSAT and European Space Agency satellites will play similar roles in GOES validation. A major post-launch airborne science cal/val field campaign was conducted in the spring of 2017 that involved NASA's ER-2 high-altitude airborne science aircraft, which carried an array of instruments that collect data related to those collected by GOES-16.

A major consideration for cal/val success across all Earth-observing satellites is achieving compatibility of data from legacy missions with those from new missions—a high priority for conducting climate change research to ensure continuity of the datasets.

A major consideration for cal/val success across all Earth-observing satellites is achieving compatibility of data from legacy missions with those from new missions—a high priority for conducting climate change research to ensure continuity of the datasets. NASA and NOAA collaborate closely on these efforts since legacy data are the result of legacy algorithms and instrument technologies, in part contributed by NASA. A video describing the GOES-16 cal/val efforts can be found at *https://youtu.be/rCTIkSM2r44*.

Data Product Generation and Distribution

To insure that the advanced data produced by GOES-16, its successors, and NOAA's complimentary polar-orbiting satellites[6] meet growing user requirements in the fields of weather and other environmental observations, NOAA continues to develop advanced data centers that archive easily accessible data. These data centers provide real- and near-real-time data for users who have immediate requirements, such as for hazard warnings. Data resources for those conducting research and long term climate studies are also available. The following is a summary of these data services.[7]

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[4] GOES-R cal/val requirements are described in *https://www.star.nesdis.noaa.gov/goesr/docs/valwkshop2014/ThurAM/04_Goodman.pptx*.
[5] To learn more about the A-Train, see "The Third A-Train Symposium: Summary and Perspectives on a Decade of Constellation-Based Earth Observations" in the July–August 2017 issue of *The Earth Observer* [**Volume 29, Issue 4,** pp. 4-18—*https://go.nasa.gov/2wcckpR*].
[6] NOAA maintains a fleet of polar-orbiting satellites that includes the Suomi National Polar-orbiting Partnership (Suomi NPP) and the Joint Polar Satellite System (JPSS) series of satellites. The first satellite in the series, JPSS-1, was launched on November 18, 2017, and was renamed NOAA-20 after successfully reaching orbit.
[7] A more detailed description of the many user-friendly data distribution services provided by NOAA can be found at *http://www.ospo.noaa.gov/Services/index.html*.

Direct Broadcast – Near-Instantaneous Data Access

The GOES Rebroadcast (GRB) is a direct-broadcast capability that provides the primary relay of full-resolution, calibrated, near-real-time data from ABI and GLM, and solar data that flow to the NOAA space and Earth environment research and operational framework. To receive these data, users can purchase the necessary equipment (antenna, receiver, computer, and software) from commercial companies for unlimited access to the GOES-16 GRB. The data can be accessed after registering at *https://dcs1.noaa.gov/Account/Login*.

Near-Real-Time Data Access

The NOAAPort broadcast system provides NOAA environmental data and information in near-real time to NOAA and external users. This broadcast service is implemented by a commercial satellite communication provider. Its primary purpose is to provide internal communications within the NWS field offices to provide forecasts, warnings, and other products to the mass media (e.g., newspapers, radio stations, and TV), emergency management agencies, and private weather services. Certain GOES-16 data products—such as space weather and some ABI data products—are not included in this system.

GEONETCast Americas is the Western Hemisphere component of GEONETCast, a near-real-time, global network of satellite-based data dissemination systems designed to distribute space-based, airborne, and *in situ* data, metadata, and some derived data products to communities that have limited access to environmental data. GEONETCast receiving technology employs off-the-shelf components that allow low-cost, widespread adoption of the service. The system is targeted at users conducting research and making policy decisions for a range of societal benefits. Any user can access the data using the specified technology. Registration to take full advantage of the services available is recommended at *http://www.geonetcastamericas.noaa.gov*.

Research-Grade and Long-Term Data Records Access

The Comprehensive Large Array-data Stewardship System (CLASS) is NOAA's premier online facility for distributing NOAA and U.S. Department of Defense (DoD) Polar-orbiting Operational Environmental Satellite (POES) data, GOES data, and their derived data products. Archived data include raw, calibrated radiances, derived mission data products and associated metadata, calibration and processing parameters, algorithm software and test data, instrument calibration data, and ancillary data used to generate mission data products. Access to these data can be achieved by registering at *https://www.class.ngdc.noaa.gov/saa/products/welcome*.

In order to meet the demand for long-term, high-value, and accurate environmental data, NOAA has consolidated several data centers—the National Climatic Data Center, the National Geophysical Data Center, and the National Oceanographic Data Center—into the National Centers for Environmental Information (NCEI). NCEI hosts and provides public access to one of the world's largest archives for environmental data that includes, atmospheric, coastal, oceanic, and geophysical data, and may be accessed at *https://www.ncei.noaa.gov*. A wide array of weather and climate parameters can be graphed and downloaded from there.

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Imagery and Related Data at a Glance

GOES imagery and animations derived from them are used in forecasts and warnings-related decision-making, and useful for quick assessments, media applications, education, and outreach (see *http://www.goes.noaa.gov*). The images include results from all 16 ABI spectral bands and can be animated over a range of time periods. The site provides a comprehensive resource for GOES East and West images over various full-disc sectors. Data from the JMA's Himawari-8 and the European Meteosat geostationary satellites can also be viewed at this site. To access unique GOES-16 space weather data as well as ABI derived products (e.g., cloud and

Even during the current extended test and check-out period, there are already a number of exciting examples of how GOES-16 data were recently used during recent disastrous weather phenomena to track and observe hurricanes and their aftermath during the 2017 Atlantic Basin hurricane season.

aerosol characteristics), see *http://www.goes-r.gov/multimedia/dataAndImageryImages.html*. The University of Wisconsin's Cooperative Institute for Meteorological Satellite Studies maintains a site that links to many GOES data products, real-time imagery, and supporting information; this site is accessible at *http://cimss.ssec.wisc.edu/goes/goesdata.html*. The Cooperative Institute for Research in the Atmosphere's Regional and Mesoscale Meteorology Branch also has a site with links to GOES data, accessible at *http://rammb-slider.cira.colostate.edu*. Both of these sites allow users to customize images and videos that can be selected by channel, geographical sectors, and time period.

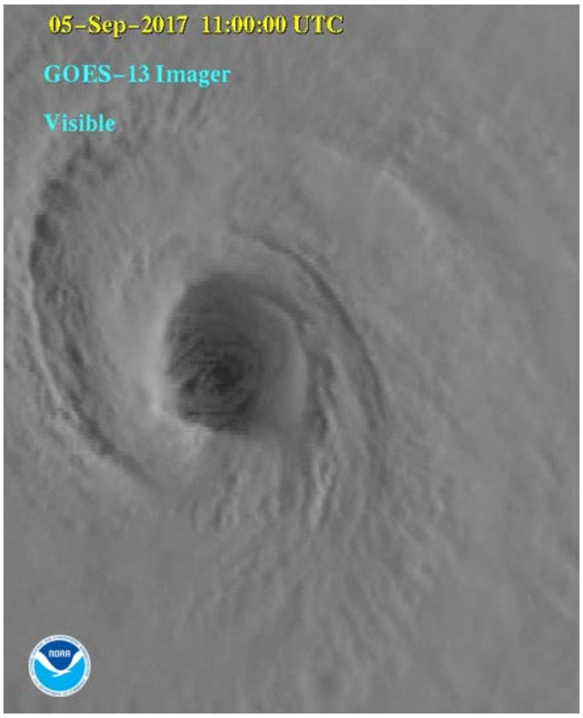
GOES as a Data Relay

The GOES Data Collection System (DCS) is a data-relay system used to transmit observations from surface-based environmental platforms through NOAA's geostationary satellites, for delivery to any platform that has the specified ground-receiving equipment. Government agencies (U.S. federal, state, local, and international) anywhere in the footprint of GOES can apply to use the system. The GOES DCS is the critical communication tool for accessing near-real-time observations. For example, this system is used to collect remote river stream flow information as well as observations associated with tsunamis over oceanic areas. Data can be accessed at and delivered from *https://dcs1.noaa.gov/Account/Login*.

Highlights from GOES-16's First Year in Orbit

Even during the current extended test and check-out period, there are already a number of exciting examples of how GOES-16 data were recently used during recent disastrous weather phenomena to track and observe hurricanes and their aftermath during the 2017 Atlantic Basin hurricane season.

A full visualization showing satellite data of Hurricane Irma from GOES-13 and GOES-16—a representative frame of which is shown in the screen grab in **Figure 4**—clearly demonstrates the improved spatial (approximately 0.5-km vs. 1.0-km) and temporal (1-min vs. 15-min) resolutions that arise from GOES-16's improvements is available at *http://cimss.ssec.wisc.edu/goes/blog/wp-content/uploads/2017/09/IRMA_ABI_IMAGER_loop_2017248_094523_2017248_113023.mp4*.



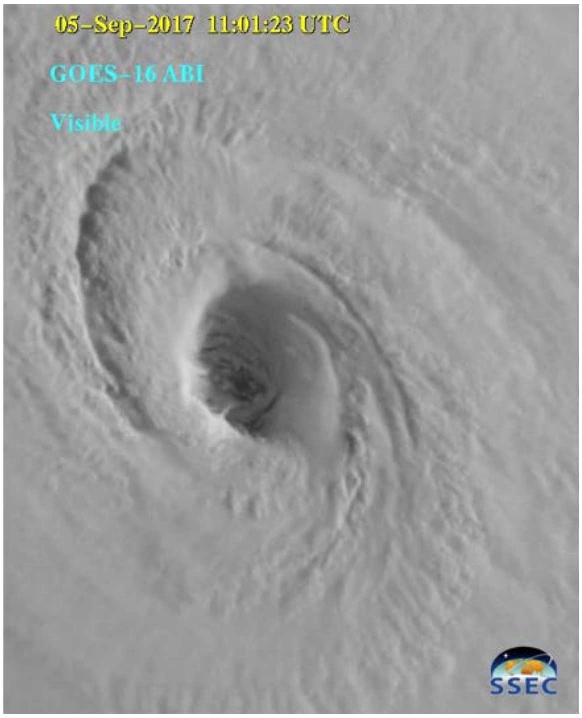


Figure 4. This figure demonstrates the increased spatial resolution of satellite data for Hurricane Irma from GOES-13 [*left*] and GOES-16 [*right*]. On previous GOES missions these high-resolution images were not routine, but with GOES-16's advanced capabilities, these images are now operational. **Image credit:** Colorado Institute for Research in the Atmosphere, Colorado State University

In September 2017 an experimental flood map using data from the Suomi NPP satellite's Visible Infrared Imaging Radiometer Suite (VIIRS) instrument and GOES-16's ABI were used to inform the U.S. Federal Emergency Management Agency as to where optimally to deploy limited resources during the floods caused by Hurricane Irma in Florida. The map—see **Figure 5**—was developed by scientists at George Mason University in Virginia, with NOAA support. To read the full story and to see additional experimental flood maps highlighting flooded land caused by hurricane Harvey, visit *https://www.nesdis.noaa.gov/content/noaa-satellites-and-aircraft-monitor-catastrophic-floods-hurricane-harvey-irma*.

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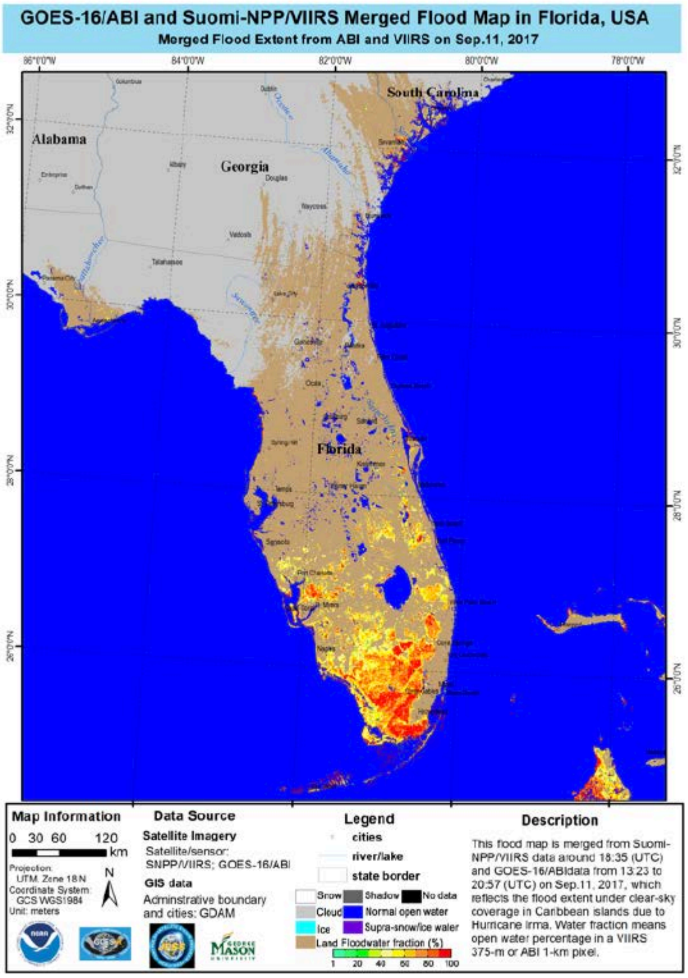

Figure 5. This flood map is merged from Suomi NPP VIIRS data around 1835 UTC and GOES-16 ABI data from 1323 to 2057 UTC on September 11, 2017. The map reflects the flood extent under clear-sky coverage in Florida due to Hurricane Irma. **Image credit:** George Mason University

Another recent example—see **Figure 6**—shows infrared data from GOES-16 being used to keep a watchful eye on Hurricane Maria as it made landfall in Puerto Rico—visit *https://youtu.be/DDgob-vR2Hg*. Visualizations from GOES-16 were used extensively by the media and the public when reporting the track of Hurricane Maria.

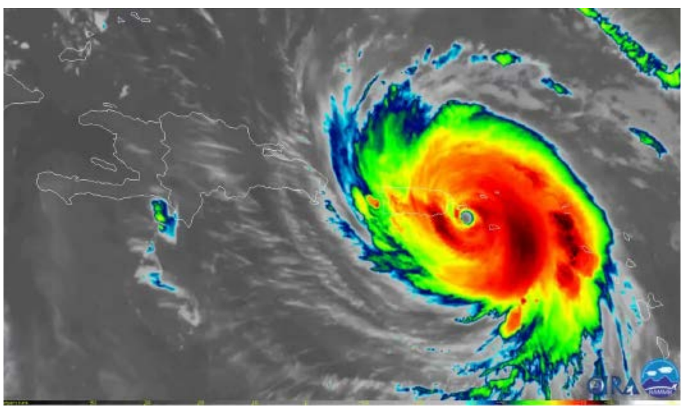

Figure 6. GOES-16 captured this infrared image of Hurricane Maria over Puerto Rico on September 20, 2017. **Image credit:** Colorado Institute for Research in the Atmosphere, Colorado State University

Another example shows lightning associated with a severe weather event over the Mississippi Valley and U.S. Southern Plains in April 2017, observed by GOES-16's GLM—see **Figure 7**. The storms produced widespread heavy rain and winds, which brought about flash flood conditions and downed trees that left thousands without power. Media reports say the storms caused the deaths of 13 people. To watch the full visualization, visit *https://www.youtube.com/watch?v=Uf9C-yr9iaA*.

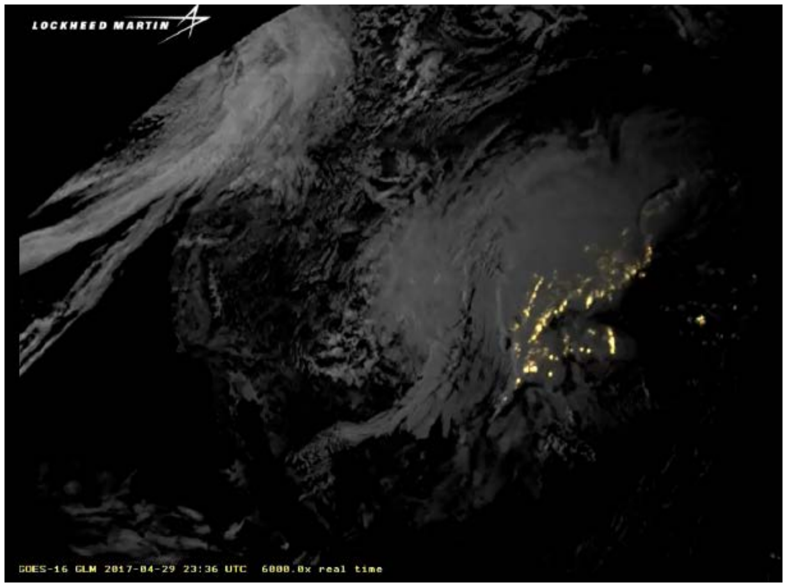

Figure 7. This image, created using data from GOES-16's GLM, shows lightning associated with a severe weather event over the Mississippi Valley and U.S. Southern Plains. The full visualization (URL provided in the main text) begins at approximately noon on Friday, April 28, 2017, and ends at midnight on Saturday, April 29. **Image credit:** Lockheed Martin

Summary

The NOAA-NASA GOES-R Series program consists of a system of environmental satellites in geostationary orbit that provide continuous weather imagery and monitoring of meteorological data for North and South America, the Caribbean, and most of the Atlantic and Pacific Ocean basins. The GOES-R Series satellites carry several advanced instruments with refined capabilities that allow scientists to study the environment and provide atmospheric, oceanic, and climatic data, supporting weather forecasting and warnings, climatologic analysis and prediction, ecosystems management, and support safe and efficient public and private transportation. Specifically, GOES-16 carries instruments to measure lightning intensity for storm warnings and public safety, and to characterize space weather, to protect the nation's electrical grid, air and space transportation and communication systems. The spacecraft has the capability to send data directly or in near-real time for emergency weather alerts to any appropriately located user that has the necessary equipment. GOES-16 also can act as a data collection platform relay and can rebroadcast emergency weather communications, and has the capability to support satellite-aided search and rescue. The GOES-16 mission has already demonstrated these capabilities by significantly improving the detection and observation of environmental phenomena that directly affect public safety, protection of property, and economic health in general just during the mission's initial and extended checkout period.

"We hear over and over from users that GOES-16 is truly transformational and a game changer for weather forecasts and warnings. With its increased capability, GOES-16 now makes it possible to observe 'weather as it happens' and this will save lives and property throughout the Western Hemisphere."—**Steve Goodman** [NOAA—*GOES Chief Program Scientist*]

The mission's capabilities are further enhanced through NOAA's collaborations with international space meteorological agencies that ensure satellite data products are compatible for utility, worldwide. A large part of the GOES program's success is due to the close partnership with NASA and close collaboration in many phases of the mission. The next in the series, GOES-S, is planned for launch in March 2018; GOES-T and -U will follow, ensuring geostationary environmental data through 2036. In collaboration with NASA, GOES-16 data products are undergoing a comprehensive cal/val program. As of this writing GOES-16 is not yet operational, but will begin a two-week drift on November 30 to its operational position at 75.2° W and begin operations in January 2018 to replace GOES-13, which will then go into storage at 60° W (as explained in Figure 2). Meanwhile, GOES-S, the second satellite in the GOES-R series, is now at NASA's Kennedy Space Center, and preparing for launch in early 2018. ■

GLOBE Observer: Citizen Science in Support of Earth System Science

Holli Riebeek Kohl, NASA's Goddard Space Flight Center, holli.a.riebeek@nasa.gov

Introduction

Imagine having an army of people collecting validation data to support your research, *at no cost to your project!* The idea behind *citizen science* is to marshal science-interested volunteers to participate in the scientific process, usually through gathering or analyzing data. Citizen science is not new, but recent advances in computing have brought increased value to crowd-sourced data collection and analysis.

An example of a citizen-science program—designed to support Earth system science—is the Global Learning and Observations to Benefit the Environment (GLOBE) Program. Initially conceived as an educational program, GLOBE has now expanded to accept measurements from citizen scientists. Citizen scientists who contribute to GLOBE may do so through trained field work or by making simple observations through a smart-phone app called *GLOBE Observer*.

The GLOBE Program

The GLOBE Program, which includes the GLOBE Observer, is an international science and education program that provides students and the public worldwide with the opportunity to participate in data collection and the scientific process, and contribute meaningfully to our understanding of Earth's systems and the global environment. Announced by the U.S. government on Earth Day in 1994, GLOBE launched its worldwide implementation in 1995. GLOBE is sponsored by NASA with support from the National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA), and U.S. Department of State. Internationally, GLOBE is implemented through government-to-government agreements, with each country-partner responsible for in-country activities.

The GLOBE Program, which includes the GLOBE Observer, is an international science and education program that provides students and the public worldwide with the opportunity to participate in data collection and the scientific process, and contribute meaningfully to our understanding of Earth's systems and the global environment.

GLOBE connects students, teachers, scientists, and citizens from different parts of the world to conduct useful, hands-on scientific activities relevant to their local environments. GLOBE provides specific protocols to collect observations of 40 different environmental parameters in the atmosphere, biosphere, hydrosphere, and pedosphere. The protocols were designed by scientists to ensure the most accurate data collection possible for each parameter. Most protocols match some aspect of remote sensing and were meant to be used for data verification.[1]

In its initial implementation, GLOBE teachers had to be trained in the GLOBE protocols, and register their school in GLOBE, before participating. Each school receives their own page on the GLOBE website, where data collected by their students are displayed. The page includes student accounts that give students full access to enter data or collaborate with other schools. The school site includes contact information for the educators so that teachers can reach out to other schools that are using GLOBE, enabling international collaboration.

Teachers may choose to lead students in one or more of the protocols, selecting those that best support their content standards and grade level. Students or citizen scientists (i.e., those who have taken GLOBE training) may also select protocols as a basis for their own research. Student research can be shared in local events, such as a regional GLOBE Science Research Symposium in the U.S., or the International Virtual

[1] Verification is being used in lieu of the more familiar validation to imply less rigor.

As a large and long-running international citizen-science program, GLOBE has collected approximately 145 million data points from students and citizen scientists in 119 countries.

Science Symposium, which provides an online forum for students from all GLOBE countries to present their work.[2]

As a large and long-running international citizen-science program, GLOBE has collected approximately 145 million data points from students and citizen scientists in 119 countries. Despite this number, large data gaps still exist. For example, students collect data at schools in their localities, leaving geographic holes. Temporal data gaps exist because data are typically collected only while students are in school, and often only when the class is covering a particular science unit.

To increase data density and improve the usefulness of the data to the science community, the GLOBE Program decided to open its doors to nonstudent citizen scientists in 2016. Citizen scientists are permitted to take GLOBE training, just as a teacher would, to make the same environmental measurements as would a GLOBE teacher or student. The training is available online and in person. However, training presents a barrier to entry. Wanting to encourage widespread citizen science data collection, GLOBE implemented a simplified version of select protocols in a smartphone app called GLOBE Observer. A citizen scientist can make observations through the app with relatively little training and by undergoing a much simpler registration process.

GLOBE Observer

GLOBE Observer

In the year since its launch, GLOBE Observer has indeed expanded the GLOBE Program to nonstudent audiences, making it much simpler for anyone to collect data with minimal training and little-to-no equipment. The GPS technology also removes some of the complexity of data collection, such as the real-world location of the data, or *geolocation*. The GLOBE Observer app works on iPhones and Android devices and is available for free in the App Store and Google Play.

By opening GLOBE to a wider citizen-science audience, GLOBE Observer hopes to:

- increase data density both spatially and temporally;
- improve access to GLOBE data for scientists, including the parameters necessary to assess data quality;
- improve access to GLOBE data for students and citizen scientists;
- help citizen scientists feel that they are part of the international GLOBE community and to engage in a bigger purpose (Earth system science); and
- help citizen scientists gain science literacy, potentially to include an increased perception of themselves as scientists.

GLOBE Observer transfers select GLOBE protocols to the app environment, eliminating the need for equipment or extensive training. The app guides users through the process of taking data, complete with descriptions of how the app is used.

GLOBE Observer officially launched on August 31, 2016, with the cloud protocol (described later). It was expanded in the spring of 2017 to include a mosquito habitat

[2] Reports from the 2017 International Virtual Science Symposium can be found at *https://www.globe.gov/news-events/globe-events/virtual-conferences/2017-international-virtual-science-symposium/virtual-science-symposium-reports*.

mapping protocol—see **Figure 1**. It also included a temporary solar eclipse protocol based on the cloud protocol that was open for data collection August 18-21, 2017. A land-mapping protocol will be added in late 2017 and early 2018.

GLOBE Observer Clouds

In the cloud protocol, citizen scientists classify clouds and percent cloud cover. When beginning an observation, the app automatically records the time, date, and latitude and longitude at the data-taking location. A map is provided so that the citizen scientist can correct or enter a location if the phone's location services aren't working. The user then indicates whether they see clouds, a clear sky, or an obscured sky (i.e., clouds obscured by rain, fog, smoke, etc.). If clouds are observed, then the app asks the person to report percent cloud cover in a range (0-10 %, 10-25 %, and so on), sky color, and visibility. The app helps the citizen scientist identify cloud type, percent cloud cover, and cloud opacity for high clouds, mid-level clouds, and low clouds. Surface conditions are selected on a yes/no basis with regard to snow cover, standing water, mud, dry ground, leaves on trees, and type of precipitation (e.g., rain or snow). Finally, the citizen scientist takes six photos, facing north, south, east, west, up, and down—see **Photo**.

The data are stored locally until the user reviews and submits the data. This enables a citizen scientist to use the app offline in a remote area and then share data once there is access to the Internet, or a strong cellular data connection.

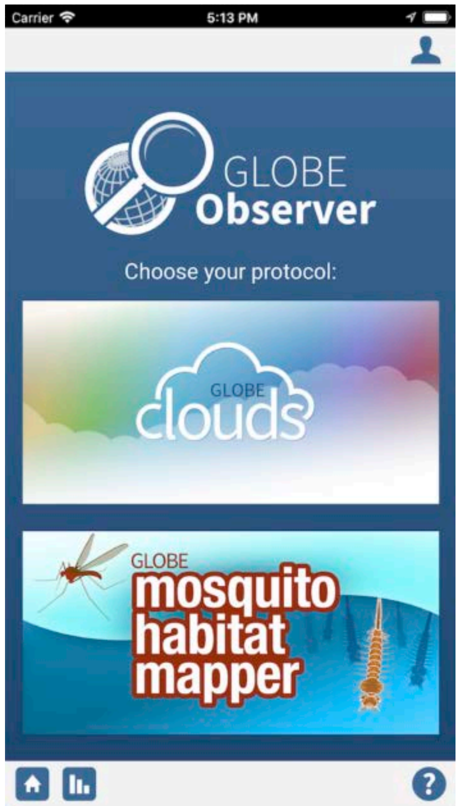

Figure 1. The home screen of the GLOBE Observer app as viewed on a smart phone. **Image credit:** GLOBE

Photo. Citizen scientist takes a photo of clouds at their location. **Photo credit:** Jennifer Campbell, GLOBE

The app provides overpass times for the satellites that GLOBE Observer data are to support and will alert the citizen scientist when to take observations if this feature is enabled. If the data were taken during a satellite overpass, the citizen scientist will receive an email with the corresponding satellite data for their own use.

GLOBE Observer Mosquito Habitat Mapper

The Mosquito Habitat Mapper leads the user through a decision tree to identify natural and artificial mosquito breeding areas. The user photographs the site, and then the app leads the user through the steps required to take a sample of the water to pull out mosquito larvae. In the optional second half of the protocol, the citizen scientist is guided through the process of photographing the larvae and identifying the genus. Finally, the app provides suggestions for mitigating the site, such as removing trash, or dumping or treating water in other places where water pools.

GLOBE Observer Solar Eclipse Protocol

The temporary eclipse protocol (available only on August 18-21, 2017) was designed to take data for the total solar eclipse on August 21, 2017. It requested air temperature and cloud observations starting at *first contact* (the moment that the moon's shadow made contact with the sun, i.e., the beginning of the eclipse) and ending at *last contact* (when the moon's shadow moved past the sun, i.e., the end of the eclipse). More than 106,000 data points were submitted to GLOBE through the eclipse protocol—see *How Cool was the Eclipse?* on page 18.

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How Cool Was the Eclipse?

"How cool was the eclipse?" That is the question GLOBE Observer posed to citizen scientists across the U.S. in August 2017. The eclipse protocol asked citizen scientists to observe changes in air temperature and cloud cover during the total solar eclipse on August 21. Cloud cover acted as a proxy for changes in temperature in the atmosphere. The app requested participation wherever the sun was eclipsed to any degree, which included all participants in North America.*

The eclipse experiment had three goals: to provide useful scientific data to get at underlying questions about Earths' energy budget by recording the direct impact of a decrease in solar energy during the eclipse; to use the eclipse as an opportunity to educate a broad audience about the sun-Earth relationship (i.e., to communicate the idea that Earth is solar-powered, and that changes in solar energy directly impact weather and temperature); and to create a robust dataset that students could use for student research projects.

Recruiting Citizen Scientists

The success of the eclipse protocol depended on getting enough participants within the path of totality (where the moon completely covered the sun) and also outside the path of totality. The experiment was broadly advertised through NASA Communications activities, news interviews, social media, education partners like libraries, museums, the GLOBE Program, and eclipse-related public events. These efforts had an estimated potential reach exceeding 11 million. By August 21 about 50,000 new users had registered to use the GLOBE Observer app, more than tripling the app's pre-eclipse user base.

Scientific Data Collection

To enable data collection on the day of the eclipse, a temporary eclipse protocol was developed within the GLOBE Observer app. The protocol showed citizen scientists how and when to collect temperature and cloud observations on the day of the eclipse, enabling their participation in the eclipse experiment. The eclipse portion of the app was active a few days ahead of and during the eclipse. The app automatically recorded the citizen scientist's location and used it to determine the time of first contact, maximum eclipse, and last contact. The app used this information to alert the user when it was time to record the temperature or cloud cover.

In preparation for the eclipse, the citizen scientist was asked to calibrate an air temperature thermometer in an ice slurry. The thermometer was then hung in the shade or held at arm's length in the shade during the experiment.

The app asked the citizen scientist to observe temperature and cloud cover immediately before the moment the moon first moved in front of the sun (first contact). In this first data collection point, the citizen scientist reported what kind of thermometer he or she was using and set the scale to Fahrenheit or Celsius. The app asked for repeat temperature measurements every 10 minutes initially, increasing to five-minute frequency for the hour around maximum eclipse.

To record cloud cover, the app asked citizen scientists to use the existing cloud protocol. It asked for cloud observations every 30 minutes initially, and every 15 minutes during the hour surrounding maximum eclipse. Citizen scientists were also encouraged to make an observation any time they noticed a change in cloud cover.

The app did not request data collection during totality or maximum eclipse, so as to allow participants to enjoy this rare event.

As individuals recorded data, the app provided a line graph so that the citizen scientist could chart their temperature in real time—see **Figure 2** (next page). The app also provided an animated map of temperature data across the U.S. that updated in real time. This allowed users to see temperatures cool along the path of totality as the eclipse progressed.

All data were recorded in the GLOBE Observer app and automatically sent to GLOBE when the smart phone had a strong WiFi or data connection. The data are therefore stored in the GLOBE database, where they are accessible to everyone with appropriate access.

Looking Forward: Data Analysis

There were nearly 83,000 temperature observations generated during the eclipse, and 20,000 cloud observations from sites across North America—see **Figure 3**. The GLOBE Observer analysis team compared temperatures reported by citizen scientists using the GLOBE Observer app to those reported by trained personnel in the same region. The average temperatures reported by citizen scientists were comparable to scientists' measurements, providing confidence in the citizen science data. The team also matched the cloud observations to concurrent satellite data, where possible.

Citizen scientists reported a change in temperature of as much as 20 °C (36 °F). In general, the greatest temperature change was seen in the path of totality, where skies were clear. Locations that reported cloudy skies had a smaller temperature change or no change at all.

To encourage scientists, students, and citizen scientists to integrate the data into their research or to be mined for additional insights, GLOBE Observer is providing data files at *https://observer.globe.gov/science-connections/eclipse2017/data-analysis*. The data are available in the GLOBE database as well, but the files on the GLOBE Observer site are intended to make that dataset easier to access.

Looking forward, GLOBE Observer is working with the GLOBE Program to invite students to use the eclipse data in science research submitted to the GLOBE Student Science Symposia. These regional research events are held across the U.S. Students may also participate in the International GLOBE Virtual Science Symposium.

If you are interested in using the data or coaching students to use the eclipse data, please email *globeobserverhelp@lists.nasa.gov*.

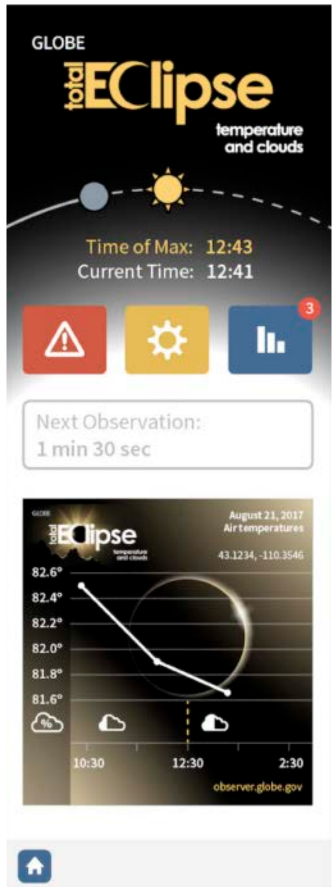

Figure 2. The GLOBE Observer eclipse protocol provided a real-time graph of temperature change at the user's location. **Image credit:** GLOBE

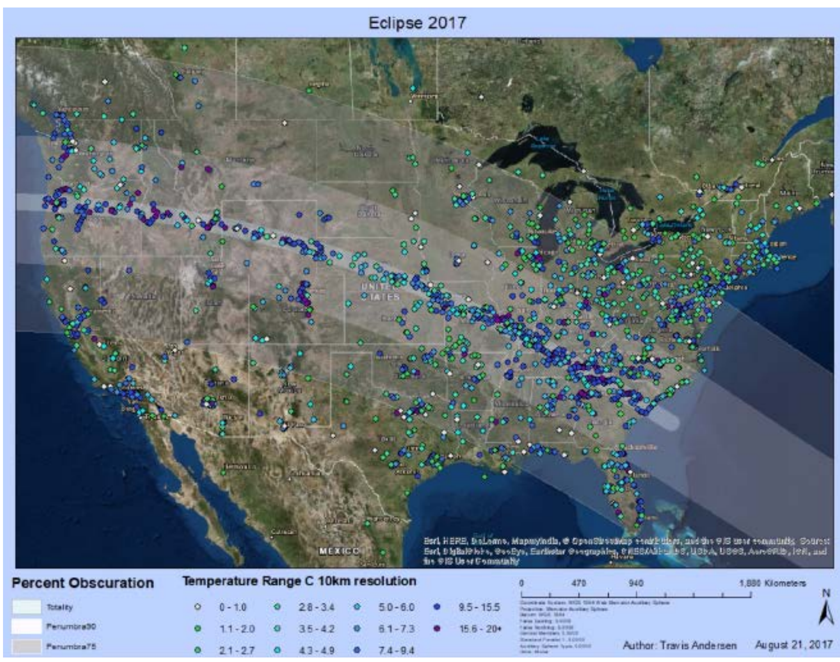

Figure 3. This map shows the change in temperature over a 10-km (~6-mi) grid. All citizen science observations in each 10-km region were averaged to yield a regional temperature change. **Image credit:** Travis Anderson, GLOBE

*To learn more, see "NASA Provides Unique Views of the 2017 'Eclipse Across America'" in the September–October 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 5**, pp. 4-17—*https://eospso.gsfc.nasa.gov/earthobserver/sep-oct-2017*]. The article includes an example of the GLOBE Observer Eclipse Protocol being used in Oregon—see *Clouds in a Bottle but Smoke-Free Skies Above* on page 7 of the article.

Data Access for Science

All GLOBE data, including GLOBE Observer data, are stored in the GLOBE database, where scientists, students, and citizen scientists can access it. To preview the geographic distribution of the data, go to the GLOBE Visualization System at *https://vis.globe.gov/GLOBE*. Click on *Add* and select the data layer you want to see. You can filter the data by date, location, elevation, or by observer.

To access the data, go to the GLOBE Advanced Data Access Tool at *https://datasearch.globe.gov*. Select data filters (available from the menu on the left) to request specific data types (clouds, mosquitoes, etc.). Data can be filtered by date and location. The tool will allow individuals to get a summary data table or a full spreadsheet that includes all of the data recorded for a particular protocol. The GLOBE Observer team is working on a user interface that will allow scientists to export the data in batches in the near future.

Scientists' Participation in GLOBE

GLOBE and GLOBE Observer tools are not meant solely for nonscientists. Scientists can participate in GLOBE and GLOBE Observer by submitting observations and by using GLOBE data to support their own research. The GLOBE Observer team is especially interested in forming partnerships with scientists who use GLOBE data. For example, scientists at NASA's Langley Research Center are using citizen observations of clouds to verify classification of certain parameters in cloud data products from the Clouds and the Earth's Radiant Energy System (CERES) instrument and Geostationary Operational Environmental Satellite (GOES) satellites. Another group of scientists is integrating Mosquito Habitat Mapping data and satellite data (Aqua AIRS, MODIS NDVI, MODIS surface temperature, GPM precipitation, SRTM)[3] into models that predict vector-based disease outbreaks. Scientific journal articles that reference GLOBE can be found at *https://www.globe.gov/do-globe/publications*.

Another way to support GLOBE is by joining the GLOBE International STEM Network, *https://www.globe.gov/join/become-a-globe-scientist*, through which scientists and other STEM professionals collaborate with students and citizen scientists by reporting on how GLOBE data are used in scientific research and helping to guide student-level research.

In addition to partnerships with scientists currently using GLOBE data, the GLOBE Observer team is very interested in engaging the science community in additional research. If as a scientist you use GLOBE data to support your research, or you are interested in using GLOBE data, please tell us by emailing *globeobserverhelp@lists.nasa.gov*.

Most citizen scientists volunteer to collect scientific data because they want to contribute to the growing fund of scientific knowledge. You can participate, too. By reporting your formal research to the community of citizen scientists who are collecting data, you provide the positive feedback necessary to motivate their ongoing participation. Your research with GLOBE data can also inspire hundreds of young primary school scientists for whom the program is their initial taste of real scientific research.

What's Next for GLOBE Observer?

As of August 31, 2017, over 69,000 people had downloaded the GLOBE Observer app. During GLOBE Observer's first year, citizen scientists collected 702 mosquito habitat observations, 63,871 cloud observations, and 82,727 temperature observations from the eclipse.

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[3] AIRS stands for Atmospheric Infrared Sounder; MODIS stands for Moderate Resolution Imaging Spectroradiometer; NDVI stands for Normalized Difference Vegetation Index; GPM stands for Global Precipitation Measurement; and SRTM stands for Shuttle Radar Topography Mission.

In 2018 GLOBE Observer is focusing on deploying a land protocol, including both land-cover classification and tree height, and building communities of scientists, citizen scientists, and educators around each of its protocols. GLOBE Observer is especially looking to build science and applications user communities around clouds, mosquito habitat, and land cover.

The new land protocol will ask citizen scientists to photograph a landscape in all four cardinal directions, up, and down. The citizen scientist will then identify the primary land-cover types visible in the photo. The high-level land-cover types will include closed forest, woodland, tall shrubs and thicket, short shrubs and thicket, herbaceous vegetation, barren, wetland, open water, cultivated land, urban, and snow and ice. The app will ask the citizen scientist to estimate what percent of the land has that land-cover type. The top-level classifications and percent cover data will then be available to scientists to match with the land-cover classification system of their choice. The protocol may include a quality assurance step through which others can identify land-cover types in the photos to verify the citizen-scientist observation.

As GLOBE and GLOBE Observer move forward and mature, the scientific community increasingly will have opportunities to request specific observations from and to interact with citizen scientists.

The land protocol may also include a tree-height calculator that will use the phone as a clinometer to estimate tree height. This protocol is being developed in collaboration with scientists supporting NASA's Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) mission. It is intended to provide verification data for the ICESat-2 mission.

Conclusion

GLOBE is a long-standing program that needs ongoing support from the scientific community to sustain citizen science motivation. It is a potentially rich source of data for verification for any environmental science research. It is also a powerful educational tool for students and adults, especially when well supported with results from formal scientific research. As GLOBE and GLOBE Observer move forward and mature, the scientific community increasingly will have opportunities to request specific observations from and to interact with citizen scientists. The program eagerly solicits and welcomes participation in its growing community. ■

announcement

SAGE III-ISS Makes First Public Data Release

In late October 2017, the Atmospheric Sciences Data Center (ASDC) at NASA's Langley Research Center announced the first release of data products from the Stratospheric Aerosol and Gas Experiment III on the International Space Station (SAGE III-ISS).

Launched on February 19, 2017, on a SpaceX Falcon 9 from NASA's Kennedy Space Center and subsequently mounted externally on the ISS, SAGE III-ISS uses a technique known as occultation. This approach involves looking at the light from the sun or moon as it passes through Earth's atmosphere at the edge, or limb, of the planet to provide long-term monitoring of ozone vertical profiles of the stratosphere and mesosphere. The data provided by SAGE III-ISS include measurements of key atmospheric constituents and their long-term variability, including aerosols, chlorine dioxide, clouds, nitrogen dioxide, nitrogen trioxide, pressure and temperature, and water vapor. SAGE data have historically been used by the World Meteorological Organization to inform their periodic assessments of ozone depletion. These new observations from the ISS will continue the SAGE team's contributions to increasing our scientific understanding of Earth's atmosphere.

The initial release of SAGE III-ISS products focuses on solar occultation. While not included initially, later releases will include lunar occultation and water vapor data. Subsequent data releases will follow a monthly release schedule.

To learn more, visit the ASDC website at *https://eosweb.larc.nasa.gov/news/sageiii-iss-data-release*.

First TROPICS Applications Workshop Meeting Summary

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Introduction

The Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission (*https://tropics.ll.mit.edu/CMS/tropics*) is a constellation of six state-of-the-science observing platforms that will acquire temperature and humidity soundings and perform precipitation-related measurements with unprecedented frequency, as described later in this article. NASA selected the mission as the winning proposal for the Earth Venture[1]–Instrument (EVI-3) Announcement of Opportunity in 2016. **William Blackwell** [Massachusetts Institute of Technology Lincoln Laboratory (MIT LL)] is the principal investigator for TROPICS.

The Applied Sciences Program of NASA's Earth Science Division convened the first TROPICS Applications Workshop, May 8-10, 2017, at the University of Miami's Rosenstiel School of Marine and Atmospheric Science Auditorium in Miami, FL, to enable a conversation between the mission developers, the science team, and end-users in the applications community.

While the primary mission objective for TROPICS is related to tropical cyclone intensity, there are other application areas where observations from TROPICS may be valuable. Thus, the TROPICS Applications Workshop focused on several specific objectives, which were to:

- introduce a broad community of potential end-users to the expected value of the TROPICS mission by reviewing mission specifications and status;
- review TROPICS data applications through presentations and breakout discussions;
- provide a forum for applied researchers and operational decision makers to share insights into how observations from TROPICS can be used by their organizations and potential challenges to their application; and
- form a user community that can highlight potential TROPICS applications and accelerate post-launch applications.

[1] Earth Venture (EV) missions were implemented following the 2007 Earth Science Decadal Survey. They are stringently cost-capped missions that are divided into three categories: full mission (EVM), instrument (EVI), and suborbital (EVS).

The TROPICS Science Team seeks to fulfill these specific objectives before final mission formulation—two-to-three years prior to the expected mission launch date, which is no earlier than 2020—in order to demonstrate its commitment to maximizing the return on NASA's investment.

Mission Details

While TROPICS will have a spatial resolution comparable to current operational passive microwave sounders, what makes TROPICS potentially game-changing is its proposed 45-minute median temporal refresh. This represents a significant improvement in temporal resolution over the three-hour temporal resolution of existing sensors, and should lead to more data being obtained and incorporated into models, with consequent improved ability to track quickly evolving changes within tropical cyclones over their entire life cycles.

The overarching goal for TROPICS measurements—shown schematically in **Figure 1**—is to provide nearly all-weather observations of three-dimensional temperature and humidity, as well as cloud ice and precipitation horizontal structure, at high temporal resolutions. This will be done by studying:

- relationships between rapidly-evolving precipitation and upper cloud structures with upper-level,

Figure 1. Artist's rendition of the TROPICS mission concept showing the constellation of SmallSats and representations of several aspects of their observing capabilities. Each satellite will measure all three of the data samples shown here. Swath width for TROPICS will be 2025 km (~1258 mi). The nadir spatial resolution of TROPICS will be 27 km (~17 mi) for temperature, 17 km (~11 mi) for moisture and precipitation, and 35 km (~22 mi) for 90-GHz imaging. **Image credit:** Massachusetts Institute of Technology Lincoln Laboratory

warm-core intensity and associated storm intensity changes;

- evolution of precipitation structure and storm intensification in relation to environmental humidity fields; and
- the impact of rapid-update observations on numerical and statistical intensity forecasts for tropical cyclones.

The mission is comprised of a constellation of six, 3U SmallSats [approximately 10 x 10 x 34 cm (~4 x 4 x 13 in)], each hosting a 12-channel passive microwave spectrometer based on the Micro-sized Microwave Atmospheric Satellite 2 (MicroMAS-2) developed at MIT LL—see *https://tropics.ll.mit.edu/CMS/tropics/The-MicroMAS-2-Cubesat*. The six TROPICS SmallSats will fly in three low-Earth orbital planes (two satellites per plane) and each SmallSat will host a high-performance radiometer that will provide:

- temperature profiles, using seven channels near the 118.75-GHz oxygen absorption line;
- water vapor-profiles, using three channels near the 183-GHz water vapor absorption line;
- precipitation measurements, using imagery in a single channel near 90 GHz (when combined with higher-resolution water vapor channels); and
- characterization of precipitation-sized ice particles and low-level moisture, using a single channel near 205 GHz.

This observing system offers an unprecedented combination of horizontal and temporal resolutions to measure environmental and inner-core conditions for tropical cyclones on a near-global scale. The major leap forward in the temporal resolution of several key parameters that TROPICS is expected to provide input into advanced data assimilation systems capable of utilizing rapid-update radiance or retrieval data. The mission is on-track to deliver flight-ready CubeSats to the launch provider (to be determined) in 2019, with launch opportunities planned no earlier than 2020. The System Requirement Review and Mission Definition Review have been completed; the Preliminary Design Review is scheduled for late 2017.

Workshop Summary

The workshop included two panel discussions, a series of presentations by potential TROPICS end-users, and two breakout sessions that allowed the meeting participants to provide input on key applications-focused questions. The highlights from these activities are summarized below; more information on this workshop and its outcomes can be found at *http://tropics.ccs.miami.edu*.

William Blackwell opened the meeting and provided an overview of the mission as outlined in the *Mission Details* provided earlier. Following his introduction, the first panel discussion began. The panel focused on *data latency*, which the applications community has identified as a primary limitation for applying satellite datasets to operational decision making. The latency requirements for TROPICS in the original mission proposal were not sufficient for use by the operational community; however, the mission team expressed a commitment to finding solutions to improve such latency. Some ideas proposed by the team were to include additional university- or community-based ground stations at a cost of around one million dollars per year[2] or come up with a more localized approach to build direct broadcast antennas, which allow line-of-sight capture of real-time data, at select locations (e.g., Hawaii, Florida) at a cost of around $100K per station.

The remainder of the first day focused on presentations by end-users for the following application areas:

Terrestrial Applications. Data users from the U.S. Army Corps of Engineers and the reinsurance industry described and discussed their use of precipitation products for detecting precipitation amounts for landslides (see **Figure 2**), agriculture, and hydrologic applications. The higher temporal frequency of precipitation

[2] This cost is for an entire ground network for one year (24/7) of data downlink and processing to reduce latencies to levels needed by the operational community.

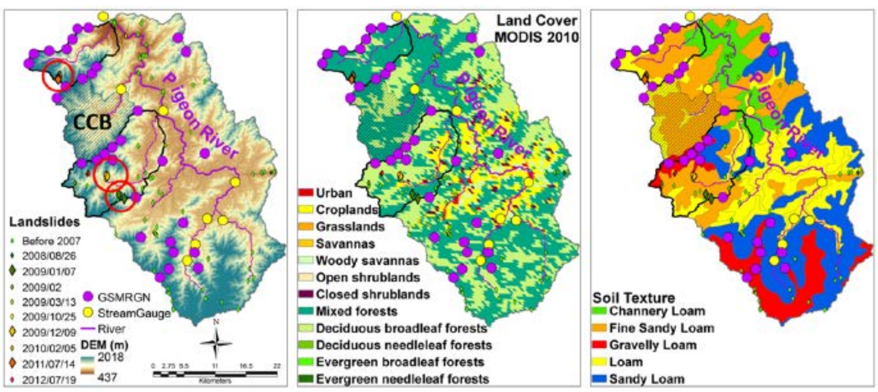


Figure 2. Overview of potential flood, debris flow, and landslide application for TROPICS. Images show the location of landslides [*left*], land cover from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra platform [*center*], and soil texture from the U.S. Department of Agriculture's Digital General Soil Map of the U.S. (STATSGO2) in southwestern North Carolina [*right*] for different high-impact severe weather events. Precipitation data from TROPICS would provide high-temporal resolution precipitation information as input to this model. To view this image in color, see the online version at *eospso.nasa.gov/earth-observer-archive*. **Image credit:** Ana Barros, Duke University

information should provide increased guidance for flood and landslide forecasting in regions where there is no good ground-based radar coverage. A key issue for these users will be to integrate TROPICS precipitation data into existing precipitation products from other sources, such as the Integrated Multisatellite Retrievals for GPM (IMERG) product generated by NASA's Global Precipitation Measurement (GPM) mission.

Tropical Cyclone Nowcasting. Representatives from the National Oceanic and Atmospheric Administration (NOAA)'s National Hurricane Center and the U.S. Department of Defense's Joint Typhoon Warning Center discussed the possibility of the operational forecasting community using brightness temperatures and imagery from TROPICS to supplement the use of data from existing passive microwave sensors to determine the location of the center of tropical cyclones and additional information regarding storm intensification, which will be easier to study and track based on the higher temporal frequency of data acquisition from TROPICS. Data latency is most important for applications related to tropical cyclone nowcasting. Operational forecasters have three-hour windows to generate their forecast products and perform coordination activities with other government agencies. If data are not available within this three-hour window, they will not be useful for operational forecasting.

Modeling and Data Assimilation. Users from NOAA's Hurricane Research Division and the team that manages the Hurricane Weather Research and Forecasting (HWRF) system described preparations to assimilate radiance observations from TROPICS into numerical forecast models, and steps to perform assimilation of the data. Microwave sounder radiances have the largest impact on global modeling systems (see **Figure 3**), so including higher temporal resolution observations should improve intensity forecasts. Applied researchers have developed a set of Observation System Simulation Experiments (OSSEs) for TROPICS that will provide feedback to the mission and attempt to develop forward operators, bias correction, error covariances, quality control, and data-thinning approaches that will accelerate the use of TROPICS data in these models.

Tropical Dynamics. Discussions in this area revolved around the use of TROPICS in identifying active convection regions, detection of signals related to the Madden–Julian Oscillation, and measuring the moisture structure of tropical cyclones to determine dynamic storm processes associated with rapid intensification. The increased temporal frequency of the TROPICS observations will allow an unprecedented look at the development and evolution of dynamic structures in tropical thunderstorms and cyclones. Additionally, the 205-GHz channel—a new spectral frequency flying aboard TROPICS—should reveal additional information about the role of in-cloud ice on tropical thunderstorm development.

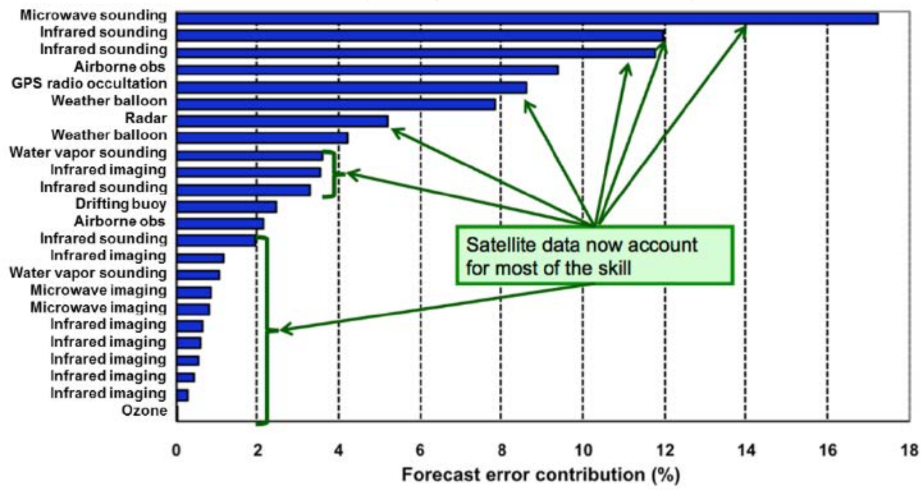


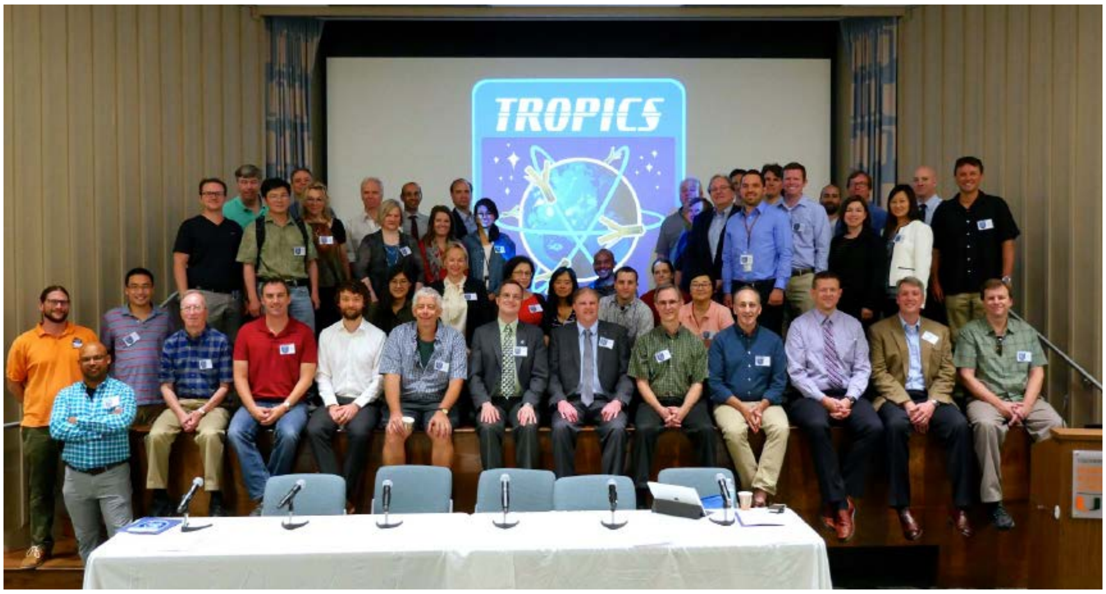
Figure 3. Impact of various observations on 24-hour European Centre for Medium-range Weather Forecasts (ECMWF) Global Forecast Skill. In the figure, larger values constitute larger impacts on reducing forecast error. **Image credit:** Erik Andersson, ECMWF

To close the first day of the meeting, the group enjoyed socializing at a reception and were able to view a demonstration of a virtual reality platform[3] to allow viewing three-dimensional atmospheric data, such as will be provided from TROPICS.

There were two breakout sessions during the morning of the second day of the meeting. The attendees self-divided into groups representing the four applications areas described earlier. The objective of the breakout sessions was to collect broader inputs on strengths and limitations of the mission concept for applications.

The meeting attendees stated that the desired temporal data frequency of the mission was between 30 minutes for flood/landslide, operational forecasting, and dynamics communities, and 3 hours for modeling and data assimilation activities. The group noted that a temporal refresh of greater than three hours does not yield benefits over the refresh rates for the current

[3] Navteca (*https://www.navteca.com*) designed the visuals as part of a NASA-funded project.



Attendees at the first TROPICS Applications Workshop held in Miami, FL. **Photo credit:** University of Miami

constellation of passive microwave sensors.[4] Desired data latency was determined to be less than one hour for real-time data use by operational forecasters and disaster monitoring, less than three hours for many modeling applications, less than six hours for agricultural applications, and greater than six hours for the applied research community.

In addition to latency, participants from the breakout sessions noted that different data formats from the standard HDF and NetCDF formats typically used by the research community are required by the different communities represented in the discussions. For example, the data assimilation community would need data in BUFR format[5] to add to their modeling systems, and many decision-making organizations require GeoTIFF datasets compatible with geospatial analysis tools.

The results from the individual breakout sessions were communicated back to the larger group in the early afternoon.

The second day concluded with a tour of the National Hurricane Center, which allowed the mission scientists and other nonforecaster participants to see a forecasting center in action, the better to understand operational activities and constraints.

[4] The Global Precipitation Measurement (GPM) Constellation allows for intercalibrated precipitation measurements. The constellation consists of the following satellites: GPM Core (NASA/JAXA), MetOp B and C (EUMETSAT), Suomi NPP (NASA/NOAA), NOAA 18 and 19 (NOAA), GCOM-W1 (JAXA), and DMSP F17, F18, F19, and F20 (DOD).

[5] The Binary Universal Form for the Representation of meteorological data (BUFR) is a binary data format maintained by the World Meteorological Organization (WMO). The latest version is BUFR Edition 4.

The third day of the workshop featured a second panel discussion that brought together leaders from missions with similar technical challenges [e.g., Cyclone Global Navigation Satellite System (CYGNSS)] or similar measurements (e.g., GPM).

The primary takeaway from these discussions was a recommendation that TROPICS data should be integrated into existing products, such as IMERG, and other data algorithms, such as the operational NOAA Microwave Integrated Retrieval System (MIRS). To close the meeting, **Bradley Zavodsky** [NASA's Marshall Space Flight Center—*Deputy Program Applications (DPA) Lead for TROPICS*] outlined a plan for quarterly teleconferences with the TROPICS applications community and development of a website to communicate to representational communities.

Conclusion

The first TROPICS Applications Workshop provided an opportunity for several potential user communities to begin to understand TROPICS data and to provide input to the mission on requirements needed to effectively use those data. Feedback regarding temporal resolution and data latency needs from the user community has been used for mission reviews to ensure that both NASA's requirements and user-community needs are considered.

The next TROPICS Applications Workshop will be held sometime in late 2018, following the development and dissemination of proxy TROPICS data products that will be obtained from the launch of prototype MicroMAS-2 satellites in December 2017. ■

Summary of the Twentieth OMI Science Team Meeting

Joanna Joiner, NASA's Goddard Space Flight Center, joanna.joiner@nasa.gov

Introduction

The twentieth Ozone Monitoring Instrument (OMI) Science Team Meeting was held September 12–14, 2017, at NASA's Goddard Space Flight Center (GSFC) in Greenbelt, MD, with nearly 80 participants. With 13 years of data from OMI (on NASA's Aura platform) now available, one aim of this meeting was to provide an update to the user community on the current status of OMI and the various OMI datasets. Another goal was to provide an opportunity for some of the younger scientists who use OMI data to present their work and get feedback from the OMI science team members who provide OMI data products.

The key highlights from each day of the meeting are presented herein. The complete list of presentations given during the meeting can be viewed on the *Meeting Agenda* page posted at *http://projects.knmi.nl/omi/research/project/meetings/ostm20.*

Day One

The first morning of the meeting began with the customary updates on instrument, product, and mission status. Both **Pieternel Levelt** [Koninklijk Nederlands Meteorologisch Instituut (KNMI), Royal Netherlands Meteorological Institute—*OMI Principal Investigator*] and **Dominic Fisher** [GSFC—*Aura Mission Director*] gave presentations on these subjects. OMI has proven to be one of the most radiometrically stable ultraviolet/visible spectrometers ever launched. Apart from well-documented *row anomaly*[1] that has reduced coverage, the instrument continues to perform well. With the row anomaly, what had been planned and implemented as daily coverage early in the mission now takes two days. The anomalous data do not present a problem, however, because they can be detected and subsequently eliminated for the purpose of scientific studies. The Aura satellite continues to perform well with all systems "in the green" and successful data capture of over 99.99%. There were also presentations on instrument calibration. **Sergey Marchenko** [GSFC] reported on the art of in-orbit calibration, while **Quintus Kleipool** [KNMI] discussed the history of inflight calibration monitoring during OMI's 13-year mission.

[1] The row anomaly is so named because it affects about half of the OMI swath (i.e., around half of its 60 rows across the swath). It is thought to have been caused when material outside of the instrument shifted to block a portion of the incoming light. This material also reflects light from outside of its field-of-view into the instrument.

The next several sessions included presentations on science results that utilized OMI trace-gas, cloud, and aerosol products. The presentations used such data to focus on air quality, emissions monitoring, and trends in trace gases that OMI measures, e.g., ozone (O_3), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). **Daniel Goldberg** [Argonne National Laboratory, University of Chicago] gave an invited presentation on a method to retrieve NO_2 at high spatial resolution using information from an air-quality model and OMI—see **Figure 1**. Several other presentations described new OMI algorithms and data products, two of which are mentioned here. **Hiren Jethva** [Universities Space Research Association] described a 12-year global record of above-cloud aerosol optical depth from OMI, and **Julien Chimot** [Delft University of Technology, Netherlands] discussed aerosol-layer height retrieval using a neural network approach.

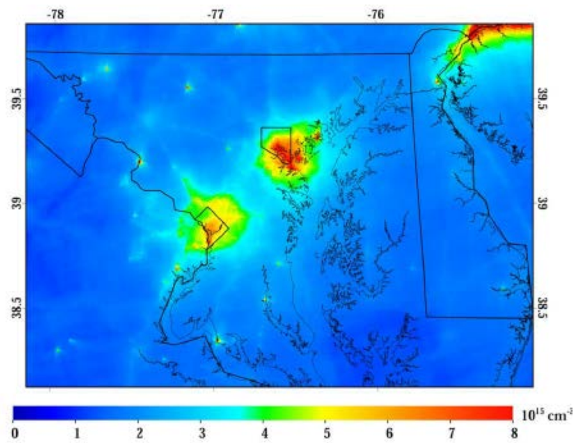


Figure 1. A new total column NO_2 product (in mol/cm^2) derived using OMI observations combined with information from a high-spatial-resolution air-quality model (called CMAQ) produces better agreement with ground-based observations than the standard product. Here, data are shown over the Baltimore, MD/Washington, DC corridor where many aircraft- and ground-based observations were made in 2011, as part of Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DSCOVR-AQ) experiment—an intensive NASA field campaign to study air quality in this area. **Image credit**: Daniel Goldberg [Argonne National Laboratory]

Simon Carn [Michigan Technological University] showed how OMI measurements of SO_2 have been used to quantify emissions from 90-100 degassing volcanoes over more than a decade, many for the first time—see **Figure 2** (next page)—and how OMI data are being used in an ongoing effort to merge data from multiple satellites into a long-term record.

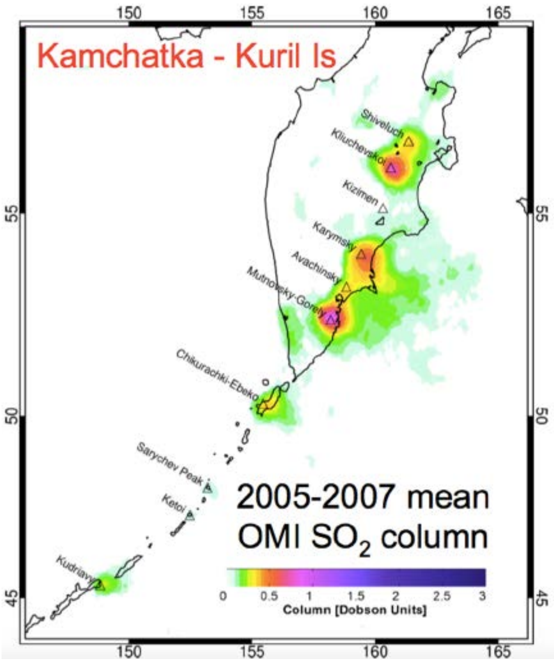


Figure 2. Recently updated total column SO_2 from OMI has been used for the first time to quantify and track volcanic emissions from remote volcanoes such as the ones shown over Russia's far-eastern Kamchatka peninsula and nearby islands. **Image credit**: Simon Carn [Michigan Technological University]

Day Two

On the second day, **Tracey Holloway** [University of Wisconsin] gave an invited presentation in which she discussed the role OMI observations play in air-quality and public-health decision making, and described the scope of the newly formed NASA Health and Air Quality Applied Sciences Team (HAQAST) that she leads. Among the other presentations on the second day, **Tim Canty** [University of Maryland, College Park] focused on the use of OMI observations in air-quality model simulations to inform air quality policy. **Fei Liu** [GSFC] and **Lok Lamsal** [USRA] gave presentations describing a study of emission trends for oxides of nitrogen (NOx). Liu's presentation focused on Chinese cities, while Lamsal's covered other regions across the globe. **Folkert Boersma** [KNMI] and **Marina Zara** [KNMI] discussed new NO_2 retrieval products from OMI measurements, and those from other instruments that are part of a European project called the Quality Assurance for Essential Climate Variables (QA4ECV).

A lively poster session took place on the afternoon of the second day. Before it began, **Joanna Joiner** [GSFC—*Aura Deputy Project Scientist*] and several other members of the OMI Science Advisory Board recognized and thanked **Anne Douglass** [GSFC] for her many years of service as the Aura Project Scientist and, before that, Deputy Project Scientist. Of particular note was her organization of Aura Science Team Meetings to promote Aura as an integrated observatory for atmospheric composition. The team also welcomed **Bryan Duncan** [GSFC] as the new Aura Project Scientist.

The poster session included updates on most of the OMI algorithms, which continue to improve even after over a decade in orbit. Recent algorithm work includes the use of information from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments,[2] and from NASA's Global Modeling Assimilation Office (GMAO) assimilation system to better quantify surface and meteorological effects in order to improve atmospheric retrievals. Other posters covered a variety of research topics, including lightning-produced NO_x species, an evaluation of pollutant emissions over the North China Plain, and characterization of smoke emission in 2015 from extreme biomass burning events over Indonesia, based on OMI and other A-Train[3] satellite observations.

Day Three

The first session of the last day focused on O_3 and its trends in both the troposphere and stratosphere. **Owen Cooper** [Cooperative Institute for Research in Environmental Sciences (CIRES), University Colorado Boulder/National Oceanic and Atmospheric Administration] gave an invited presentation on the Tropospheric Ozone Assessment Report[4] (TOAR). Cooper chairs the report's steering committee, and discussed how both OMI O_3 and NO_2 data are being used in the assessment. In another invited presentation, **Paul Newman** [GSFC] discussed how OMI and other satellite data have been used over the past several decades in World Meteorological Organization (WMO) Ozone Assessments to track stratospheric ozone before and after the historic 1987 Montreal Protocol, an evolving agreement to control and eventually eliminate chlorofluorocarbons because of their deleterious effects on stratospheric O_3.

The final session of the meeting included presentations on future missions that will fly instruments relevant to OMI. **Pepijn Veefkind** [KNMI] and **Antje Ludewig** [KNMI] discussed the European Space Agency's (ESA) Copernicus Sentinel 5P mission, which launched on October 17, 2017, and carries the TROPOspheric Monitoring Instrument (TROPOMI) instrument. **Pieternel Levelt** described a compact imaging spectrometer called TROPOLITE, which is essentially a lighter-weight version of TROPOMI. There was also discussion of three upcoming geostationary missions that monitor air quality—with expected complementary observations. **Jhoon Kim** [Yonsei University] described the Korean Geostationary Environment Monitoring Spectrometer (GEMS). **Xiong Liu** [Harvard, Smithsonian Astrophysical Observatory] described NASA's Tropospheric Emissions:

[2] MODIS flies on NASA's Terra and Aqua missions.
[3] NASA and its international partners operate several Earth-observing satellites that closely follow one after another along the same orbital "track." This coordinated group of satellites is called the Afternoon Constellation, or the A-Train, for short. For more information, visit *https://atrain.gsfc.nasa.gov*.
[4] For more information about his report, visit *http://www.igacproject.org/activities/TOAR*.

Monitoring of Pollution (TEMPO) instrument.[5] The third geostationary mission is the European Copernicus Sentinel 4 mission.

[5] For more on three geostationary missions mentioned here and their instruments, please refer to "Geostationary Orbit as a New Venue for Earth Science Collaboration" in the July–August 2015 issue of *The Earth Observer* [**Volume 27**, **Issue 4**, pp. 17-22—*https://eospso.gsfc.nasa.gov/earthobserver/jul-aug-2015*]. For an article focusing more on TEMPO, refer to "NASA Ups the TEMPO on Monitoring Air Pollution" in the March–April 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 2**, pp. 10-15, 35—*https://eospso.gsfc.nasa.gov/earthobserver/mar-apr-2013*].

Conclusion

OMI continues to perform well after more than thirteen years in orbit, and with data processing algorithms continuing to improve. A number of long-term OMI data records are being used for studies on atmospheric composition and chemistry, air quality, and climate. OMI and Aura science team meetings continue to provide opportunities for team members and collaborators from all over the world to share recent results and discuss future plans. The OMI science team plans to meet again next year in Europe; details will be set at a later date. ■

Darrel Williams Receives 2017 Pecora Individual Award

Darrel Williams had a distinguished 35-year career with NASA, focused primarily on the Landsat program. He began working at NASA's Goddard Space Flight Center in 1975 after completing his BS and MS degrees at Pennsylvania State University. In 1978 he became the Assistant Project Scientist for Landsats 4 and 5. In this role, he led a team of scientists in quantifying the improvement that could be expected in transitioning from the Multispectral Scanner System (MSS) instrument to the better spectral, spatial, and radiometric resolution of the Thematic Mapper (TM) instrument. During the controversial Landsat privatization era spanning the mid-to-late 1980s, he focused on attaining a PhD in physical geography from the University of Maryland, which he earned in 1989. In 1992, as Landsat returned to government management from Earth Observation Satellite (Company), or EOSAT, Williams was appointed the Landsat Project Scientist. He served in this role until his retirement in 2010. As Landsat Project Scientist, Williams was the catalyst behind many new innovations for the Landsat 7 mission, reflecting its emerging critical role in NASA's Earth Systems Science and Mission to Planet Earth. For example, he advocated for placing Landsat 7 and the Earth Observing System's Terra platform in 705-km (~438-mi) orbits spaced ~30 minutes apart[*] to facilitate new research that makes use of multiresolution (spatial, spectral, temporal), same-day coverage by instruments on both satellites. He also enabled research that resulted in a consistent calibration thread through the entire 45-year archive of Landsat imagery, as well as the development of a novel image acquisition plan to consistently assemble robust global, seasonal coverage.

More recently, as Chief Scientist at Global Science and Technology, Inc., Williams has explored innovative approaches to lower-cost follow-on Landsat missions and continued to support completion of the recently published history, *Landsat's Enduring Legacy*, more than a decade-long effort to compile and document the definitive history of the Landsat program. *The Earth Observer* congratulates Williams on this achievement, so emblematic of his activities.

The ***William T. Pecora Award*** *was established in 1974 to honor the memory of William T. Pecora, former Director of the U.S. Geological Survey (USGS) and Undersecretary of the Department of Interior (DoI). Pecora was a motivating force behind the establishment of a program for civil remote sensing of Earth from space. His early vision and support helped establish what we know today as the Landsat satellite program, which has created a greater than 40-year continuous record of Earth's land areas.*

The award is sponsored by DoI's USGS and NASA, and presented annually to individuals and/or groups that make outstanding contributions toward understanding Earth by means of remote sensing. This year's award was presented November 15, during the Pecora 20 Conference in Sioux Falls, SD.

To learn more about this award and this year's individual (and group) winners, visit *http://remotesensing.usgs.gov/pecora.php*.

[*] This formation became known as the Morning Constellation, and was later joined by the Argentinian Satélite de Aplicaciones Científicas-C (SAC-C).

CERES Science Team Meeting Summary

Walter Miller, NASA's Langley Research Center, Science Systems and Applications, Inc., walter.f.miller@nasa.gov

Overview

The twenty-eighth Clouds and the Earth's Radiant Energy System (CERES) Science Team Meeting was held September 26-28, 2017, at NASA's Goddard Space Flight Center (GSFC) in Greenbelt, MD. The Global Modeling and Assimilation Office (GMAO) hosted the meeting. **Norman Loeb** [NASA's Langley Research Center (LaRC)—*CERES Principal Investigator*] conducted the meeting. The major objectives of the meeting were to review the performance of CERES instruments,[1] discuss data-product validation, and highlight changes implemented in the CERES *Edition 4* data products. The two invited presenters discussed GMAO efforts to improve their models. The contributed science presentations summarized team-member progress on relevant scientific topics, and included seven talks that concentrated on the Goddard Earth Observing System Data Assimilation System (GEOS).

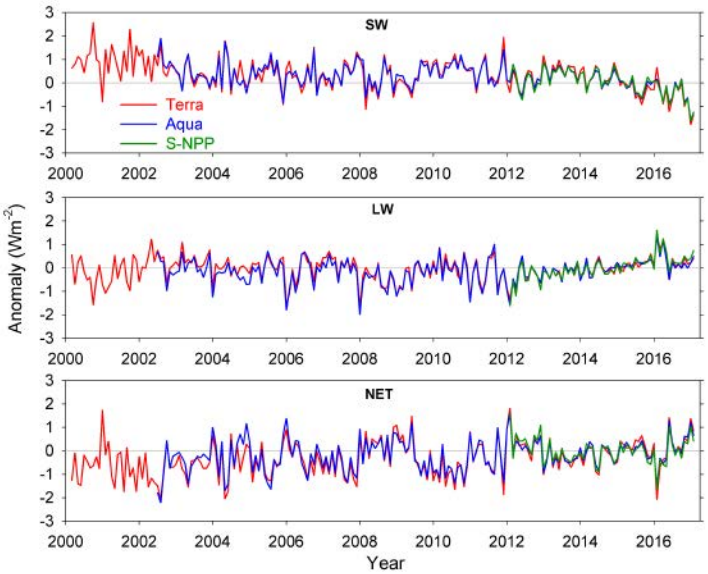


Figure 1. The global deseasonalized monthly anomalies (relative to climatological means for February 2012 through February 2017) in TOA fluxes from the Single Scanner Footprint One-degree (SSF1deg) products for CERES measurements on Terra, Aqua, and Suomi NPP, showed strong agreement for shortwave (SW) [*top*], longwave (LW) [*middle*], and net (i.e., the difference between the solar incoming and the SW and LW flux leaving the Earth at the TOA) [*bottom*] radiation. **Image credit**: Norm Loeb

Selected highlights from the presentations given at the meeting are summarized in this article. The presentations are all available online at *https://ceres.larc.nasa.gov/science-team-meetings2.php*.

Programmatic and Technical Presentations

The agenda for the first day of the meeting consisted of a series of programmatic and technical presentations given by the respective CERES Science Team working-group chairs.

Norman Loeb presented information on the *state of CERES*. He noted that there has been no change in the health of the five CERES instruments currently in orbit. The sixth flight model (FM-6) CERES instrument, planned for the first Joint Polar Satellite System Satellite (JPSS-1)[2] is at Vandenberg Air Force Base undergoing integration into the Delta II rocket and is awaiting launch, currently scheduled for November 2017. Meanwhile, the Suomi National Polar-orbiting Partnership (NPP) is the bridge between the Terra and Aqua Earth Observing System missions and JPSS, and is completing its five-year prime mission this year. **Figure 1** highlights the excellent agreement in the deseasonalized monthly anomalies in top-of-atmosphere (TOA) fluxes between the three active CERES instruments. Loeb then described the plans for the Edition 2 Suomi NPP products, which will place FM-5 on the same radiometric scale as FM-3 and will correct for the time-varying spectral response function changes that were not done in Edition 1. The Suomi NPP Visible Infrared Imaging Radiometer Suite (VIIRS) radiances will also be placed on the same radiometric scale as Aqua's Moderate Resolution Imaging Spectroradiometer (MODIS) for use in cloud property retrievals. He also announced a new collaboration with the Great Lakes Evaporation Network (GLEN), where the CERES Ocean Validation Experiment (COVE) instruments will be placed on Granite Island, MI, located in Lake Superior. COVE's former home, the Chesapeake Light Tower in the Chesapeake Bay, did not pass its latest safety inspection and cannot be used until repairs are made.

Susan Thomas [LaRC/Science Systems and Applications, Inc. (SSAI)] described the Terra Lunar Deep Space Calibration (LDSC) maneuver that occurred on August 5, 2017.[3] It will allow comparison

[1]There are currently five CERES instruments active on three satellites: two on Terra [Flight Models (FM)-1 and -2]; two on Aqua [FM-3 and -4]; and one on the Suomi National Polar-orbiting Partnership (NPP) satellite [FM-5].

[2] The Joint Polar Satellite System (JPSS) is the next member of our nation's Next-generation Polar-orbiting Operational Environmental Satellite System. The Joint Polar Satellite System-1 (JPSS-1) lifted off on a United Launch Alliance Delta II rocket from Vandenberg Air Force Base, CA, at 1:47 AM PST, November 18, 2017. JPSS is a collaborative program between the National Oceanic and Atmospheric Administration and NASA.

[3] To learn more about the Terra LDSC maneuver, see "Terra Flips for Science" in the September–October 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 5**, pp. 18-19—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Sept_Oct_%202017_color.pdf*].

with earlier LDSCs performed in 2003. During these events, which allow the instrument to look at dark space as a calibration resource, special scanning is performed to quantify scan-angle-dependent offsets for all Earth-viewing elevation angles. The offsets are a significant source of uncertainty in instantaneous sensor measurements, and showed similar trends for both periods. Thomas also reported that an Operational Readiness Review was successfully completed for FM-6 on October 4, 2017.

Anum Barki [LaRC] gave an overview of the Radiation Budget Instrument (RBI), scheduled for launch on JPSS-2 in 2021, that will continue Earth radiation budget measurements. One improvement that RBI provides over CERES is that six distinct narrowband laser-diode sources will be used to calibrate the total and shortwave (SW) detectors. RBI will also provide National Institute of Standards and Technology (NIST) traceable standards to monitor both shortwave and longwave (LW) calibration output. The Engineering Development Unit (EDU) has been completed and has undergone thermal-vacuum testing; preliminary results are all positive. A successful Critical Design Review occurred September 26-29, 2017. Barki also described development of a first-principle dynamic electrothermal numerical model for RBI. The model will be an end-to-end representation of the science signal chain (from photons on the detector to counts from the electronics). A synthetic Earth model is being developed in conjunction with the instrument model to provide the necessary radiation field characteristics.

William Smith, Jr. [LaRC] reported that initial testing with Terra MODIS Collection 6.1 (which provides compensation for crosstalk in Band 27, the water vapor channel) showed monthly cloud fraction products to have returned to good agreement with results produced using Aqua data. He also presented an evaluation of the consistency between the Suomi NPP cloud properties products from VIIRS with those produced for Aqua using MODIS. The largest differences occur during polar night, under cirrus detection conditions, and with cloud-phase determination. The algorithms that are used for these cases with MODIS involve the water vapor and carbon dioxide (CO_2) channels that are not included on VIIRS.

Wenying Su [LaRC] explored the impact of using the Aqua angular distribution model (ADM) in obtaining fluxes for Suomi NPP data. The CERES footprint size is larger on Suomi NPP due to its higher altitude and cloud property retrieval differences, caused by using a different imager (i.e., VIIRS instead of MODIS). The global mean SW flux on Suomi NPP is overestimated by 1 W/m^2, but the LW flux agrees well.

David Kratz [LaRC] reported on impacts on the parameterized surface fluxes that arise with the change from MODIS Collection 5 to Collection 6. The increase in polar nighttime cloud fraction causes larger LW surface flux in the region. Similarly, larger aerosol optical depth, especially in the tropics, reduced the SW surface flux in those regions. The latter change is considered an improvement, based on validation from ground-based observations.

Seiji Kato [LaRC] provided a comparison of the in-atmosphere heating profile in the hourly CERES Synoptic One-degree One Hourly (SYN1deg-1Hour) product with those produced using CALIPSO,[4] CloudSat, CERES, and MODIS-merged (CCCM or C3M) data products that provide higher cloud vertical resolution. The monthly zonal SW heating rates were nearly identical; the LW showed some vertical structure in differences—but were still within 1 K/day.

Dave Doelling [LaRC] briefed the team on the Flux by Cloud Type (FluxByCloudTyp) product that is in development, with an expected release in early 2018. The product will provide SW and LW fluxes for clouds in a histogram based on seven pressures and six optical depths for one-degree-latitude and -longitude regions. The algorithm will use imager radiances for each cloud within a CERES field of view (FOV) to obtain the broadband radiances and then will apply the CERES ADMs to produce SW and LW fluxes for that cloud type. This will allow detailed evaluation of clouds and radiances in global models.

Norman Loeb returned to describe the latest trends in the Energy Balanced and Filled – TOA (EBAF-TOA) Edition 4.0 product. The largest positive SW all-sky TOA flux trend occurs in the Pacific Ocean where El Niño plays a major role. The Arctic has the strongest negative SW TOA flux trend.

Fred Rose [LaRC/SSAI] announced that the EBAF-Surface Edition 4.0 product has been released. This product provides computed surface fluxes that are consistent with the EBAF-TOA product. The EBAF-Surface product takes advantage of all the Edition 4 improvements in the CERES product line. Rose described the approach being used to adjust the Terra nighttime cryosphere cloud fraction due to the MODIS water vapor channel anomaly,[5] as described earlier.

[4] CALIPSO stands for Cloud–Aerosol Lidar with Infrared Pathfinder Satellite Observations.

[5] On February 18, 2016, at approximately 2:33 PM Greenwich Mean Time (GMT), the Terra spacecraft entered safe mode during a commanding anomaly. All instruments are commanded to safe mode when the spacecraft itself is in safe mode. The CERES and MODIS instruments returned to science mode on February 24, 2017, at 5:48 PM GMT and 8:30 PM GMT, respectively.

Paul Stackhouse [LaRC] reported on recent developments of Fast Longwave and Shortwave Radiative Fluxes (FLASHFlux). The latest update, Version 4A, migrates from the current code to CERES Edition 4 clouds and inversion software. MODIS Collection 6.1 will be used as the imager data. The Time Interpolated and Spatial Average product is adapted to include additional information. The production target is January 2018. A new Prediction of Worldwide Energy Resource (POWER) website, which can be viewed on desktop, tablet, and phone, is now available at *https://power.larc.nasa.gov*.

Kathleen Moore [LaRC] announced that the generation of CERES Edition 3 products has ended as of March 1, 2017. All products are now available as Edition 4, and their forward processing will continue.

Kristen Weaver [GSFC/SSAI] described details about the Global Learning and Observations to Benefit the Environment (GLOBE) Program's efforts during the "Eclipse Across America" event on August 21.[6] The program received over 18,000 cloud observations that day, which often included photographs. The path of the eclipse can be easily identified based on the observations' locations (shown on page 19).

Invited Science Presentations

Two invited presentations began the second day of the meeting. They provided details on future directions for the GMAO.

Steve Pawson [GSFC] showed an animation that illustrated the growth of the Goddard Earth Observing System (GEOS) model that is supported by the Earth System Modeling Framework (ESMF). He noted that the so-called GEOS "FP" is the "flagship" analysis and forecasting system, now with a resolution around 12 km (~7 mi). GEOS FP implementation has pioneered the use of new data types, e.g., radiances from the Global Precipitation Measurement (GPM) mission. Version 2 of the Modern Era Retrospective-analysis for Research and Applications (MERRA)[7] is the latest reanalysis that provides half-degree spatial resolution. Improvements include interactive aerosols, enhanced representation of cryospheric processes, and use of NASA data to improve the simulation of the stratosphere. An ocean model will soon be coupled with the atmospheric model for seasonal forecasting or run without the atmosphere model to generate an analysis of ocean temperatures, salinity, and currents; this enhancement is targeted for release in 2019. GEOS also has the capability to run a three-dimensional chemistry model, but this is not yet part of the current version. Assimilation of chemical species will gradually be incorporated into the model.

Arlindo da Silva [GSFC] provided an update on aerosol modeling within the GEOS assimilation product. GMAO is developing a hierarchy of global models capable of skillfully representing the aerosol distribution and microphysical processes and their interactions with clouds and radiation. MERRA-2 is the first community model that has integrated interactive aerosols that improved the radiation budget within the model.

Contributed Science Presentations

The many contributed science presentations on the second and third days of the meeting addressed a variety of topics. These included:

- GMAO modeling efforts and evaluations;
- comparison of observations to climate models;
- validation efforts, where CERES cloud properties are compared with surface and cloud observations or other satellite products;
- improvements to existing Earth Radiation Budget products; and
- efforts to improve algorithms for future CERES products.

There was significant dialogue surrounding the presentations that tied GMAO modeling efforts and evaluations performed in the context of parameters that have the greatest impact on CERES results.

For a summary of presentations, see the **Table** on page 32.

[6] To learn more about GLOBE and the GLOBE Observer App designed for the eclipse, see "GLOBE Observer: Citizen Science in Support of Earth System Science" on page 15 of this issue. The eclipse itself is described in detail in "NASA Provides Unique Views of the 2017 'Eclipse Across America'" in the September–October 2017 issue of *The Earth Observer* [**Volume 29, Issue 5**, pp. 4-17—*https://eospso.gsfc.nasa.gov/earthobserver/sep-oct-2017*].

[7] MERRA was a NASA reanalysis for the satellite era using a major new version of the Goddard Earth Observing System Data Assimilation System Version 5 (GEOS-5). The original MERRA was discontinued on February 29, 2016, but has been replaced by MERRA, Version 2 (MERRA-2). To learn more about MERRA-2, see the "Summary of the MERRA-2 Applications Workshop" in the September–October 2017 issue of *The Earth Observer* [**Volume 29, Issue 5,** pp. 35-38—*https://eospso.gsfc.nasa.gov/earthobserver/sep-oct-2017*].

Table. List of Contributed Science Presentations at the Twenty-Eighth CERES Science Team Meeting.

Speaker [Affiliation]	**Summary**
Santha Akella [GSFC/SSAI]	Described improvements to sea surface temperature predictions achieved by assimilating radiance observations into the model, and how the surface interface changed both the atmosphere and ocean model components within GMAO's assimilation system.
Min–Jeong Kim [Morgan State University, Goddard Earth Sciences Technology and Research Center (GESTAR)]	Described incorporation of all-sky GPM Microwave Imager [GMI] data into the GMAO's assimilation that improved the lower tropospheric humidity, especially in the tropics.
Allie Collow [Universities Space Research Association (USRA), GESTAR]	Reported on some consistent diurnal and seasonal biases in the GEOS-5 2-m temperatures. There are also strong biases in certain regions.
Fred Rose [LaRC/SSAI]	Provided comparison of EBAF-Surface LW fluxes for both Edition 2.8 and 4.0 with surface observations, and explained how the GEOS 5.4.1 temperature and relative humidity contribute to the bias.
Sueng-Hee Ham [LaRC/SSAI]	Described how he ran the Fu-Liou radiative transfer model using input from four versions of GMAO assimilated data to obtain clear-sky LW fluxes at TOA and surface. The more recent assimilations showed smaller biases over tropical oceans and the eastern side of the Rocky Mountains.
Hai-Tien Lee [University of Maryland, College Park]	Compared the representation of TOA all-sky and clear-sky fluxes by three different reanalysis to Edition 4 CERES data.
Joel Susskind [GSFC]	Presented an intercomparison of Atmospheric Infrared Sounder (AIRS) Version-6 against CERES EBAF-TOA Edition 4.0 and MERRA-2 monthly Outgoing Longwave Radiation (OLR) time series over the 14-year Aqua period.
Christina Hsu [GSFC]	Provided details on the effort to generate Deep Blue Aerosol products using Suomi NPP VIIRS inputs that are consistent with the Earth Observing System's (EOS) long-term aerosol data record.
Tamas Varnai [University of Maryland Baltimore County (UMBC) Joint Center for Earth Systems Technology (JCET)]	Showed how aerosol optical thickness increases in the proximity of clouds, and is positively correlated with cloud fraction. Used an analytical model to adjust for three-dimensional enhancements resulting in lower aerosol optical depth.
Dave Rutan [LaRC/SSAI]	Showed that there is little change in the validation results using SYN1deg Edition 4 and ground sites surface fluxes from those obtained using SYN1deg Edition 3.
Nicolas Clerbaux [Royal Meteorological Institute of Belgium (RMIB)]	Reported data processing has been adapted for Geostationary Earth Radiation Budget (GERB) 2 on Meteosat 8* that is now providing cover over the Indian Ocean.
Alexander Marshak [GSFC]	Identified reflections off tiny ice platelets floating in the air nearly horizontally as the cause of unexpected bright flashes of light over land that have been seen in Deep Space Climate Observatory (DSCOVR) Earth Polychromatic Imaging Camera (EPIC) images.
Miklos Zagoni [Self]	Described how the various elements of the global mean atmospheric radiation budget can be related as simple integer ratios.
Adam Bell [Texas A&M University]	Showed that a two-habit ice model can produce cloud optical thickness and smaller effective ice diameter consistent with both the MODIS Collection 6 cloud and CERES Edition 4 results.

*Meteosat is the European Organisation for the Exploitation of Meteorological Satellite's (EUMETSAT) line of geostationary satellites.

continued on next page

Table. List of Contributed Science Presentations at the Twenty-Eighth CERES Science Team Meeting. (cont.)

Speaker [Affiliation]	**Summary**
Sunny Sun–Mack [LaRC/SSAI]	Presented a method to create MODIS-like radiances from the Cross-track Infrared Sounder (CrIS) spectral bands, thus providing "proxy measurements" for VIIRS data of the six water vapor and CO_2 channels on MODIS that VIIRS lacks.
Baike Xi [University of Arizona (UA)]	Showed that 85% of the clouds identified as single-layer mixed phase clouds by the CERES algorithms agreed with the ground-based observations at the Department of Energy's Atmospheric Radiation Measurement (ARM) North Slope of Alaska site. However, the derived tops are ~100 m (328 ft) lower than the ARM observations indicate.
Xiquan Dong [UA]	Demonstrated that CERES produced stratocumulus cloud effective temperature using GOES radiances is well correlated with the cloud-top temperature from ground-based observations at the ARM Southern Great Plains site.
Lazaros Oreopoulos [GSFC]	Showed through a cloud regime-based approach that LW and SW Cloud Radiative Effect (CRE) variability with aerosol optical depth is positive and seems very systematic.
Xianglei Huang [University of Michigan]	Looked at spectral decomposition of LW CRE using AIRS data. This statistical method helps reveal compensating biases within the overall results. The long-term and short-term cloud feedback have different spectral decomposition.
Zachary Eitzen [LaRC/SSAI]	Compared individual cloud type fluxes between the Hadley Centre's Global Environment Model version 2 (GEM2-A) model and the CERES FluxByCldType product. The GEM2-A model produces fewer and brighter clouds compared to CERES in nonpolar areas.
Brant Dodson [LaRC/USRA]	Showed that a multifaceted problem not limited to the convective parameterization exists in the convective diurnal cycle over the Amazon basin in MERRA and MERRA-2 when compared with convection information obtained from CloudSat.

Conclusion

By all accounts, the twenty-eighth CERES Science Team Meeting was very productive, with presentations about the future of GMAO models that will support CERES, the Edition 4 CERES data products, and other radiation budget instruments and products. Other presentations described how CERES data were being used to understand various atmospheric processes such as increased aerosol size when interacting with clouds, the relationship between atmospheric stability and diurnal cycle of deep convection in the Amazon, and frequency of mixed-phase clouds in the arctic. The next CERES Science Team Meeting will be held May 15-17, 2018, at LaRC. ■

Summary of the LANCE User Working Group Meeting

Diane K. Davies, Trigg-Davies Consulting Ltd., Science Systems and Applications, Inc., diane.k.davies@nasa.gov
Karen Michael, NASA's Goddard Space Flight Center, karen.a.michael@nasa.gov
Christopher O. Justice, University of Maryland, College Park, cjustice@umd.edu

Introduction

NASA's Land, Atmosphere Near real-time Capability for EOS (LANCE) makes NASA's Earth Observing System (EOS) data from various instruments[1] available within three hours of satellite overpass to meet the timely needs of applications such as numerical weather and climate prediction; forecasting and monitoring natural hazards, ecological/invasive species, agriculture, and air quality; providing help with disaster relief; and homeland security.

NASA's Earth Science Data and Information System (ESDIS) project manages LANCE, but it is steered by a User Working Group (UWG), which is responsible for providing guidance and recommendations concerning a broad range of topics related to the LANCE system, capabilities, and services. The LANCE UWG (henceforth, UWG) is composed of a representative selection of LANCE users, which meets bi-annually to review the status of LANCE and the progress made on previous UWG recommendations, and to identify and discuss potential enhancements and upgrades to the LANCE system. The UWG held its most recent meeting at NASA's Goddard Space Flight Center (GSFC) on October 3, 2017.[2]

Karen Michael [GSFC, Earth Science Data and Information System (ESDIS)—*ESDIS LANCE Manager*] welcomed the attendees. **Chris Justice** [University of Maryland, College Park—*LANCE UWG Chair*] reminded the group that the UWG's role is to:

- represent the broad community of users interested in NASA's near-real-time (NRT) data;
- review proposals for new products to be added to LANCE; and
- provide broad input on program development.

Justice anticipates that LANCE may be asked to take on new applications areas in the future. He added that NASA needs to consider how to fund the maintenance of these products in LANCE. For new missions, the user community needs to make a strong case for the use of NRT data early in the design and planning process. This was something that was also noted at the NASA Community NRT workshop in September 2016.[3]

Alfreda Hall [NASA Headquarters (HQ)] spoke on behalf of **Kevin Murphy** [NASA HQ], who could not be at the meeting. Hall noted that NASA HQ is excited about the launch of the National Oceanic and Atmospheric Administration (NOAA)-NASA Joint Polar Satellite System (JPSS) missions,[4] and Murphy confirmed that LANCE should produce the same NRT products for JPSS as are currently approved for the Suomi National Polar-orbiting Partnership (NPP) mission. NASA HQ is also excited that the ESDIS project is initiating a cloud-based data management system for data ingest, archive, and distribution; updates about this endeavor are expected to be released in the coming year.

Karen Michael gave a brief summary of LANCE. As illustrated in **Figure 1** on page 35, LANCE is a distributed system made up of data providers, known as LANCE *elements*. LANCE has an umbrella set of requirements[5] that ensure a consistent level of service for the end-user.

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[1] LANCE currently processes data from: the Atmospheric Infrared Sounder (AIRS) on the Aqua platform; the Microwave Limb Sounder (MLS) and Ozone Monitoring Instrument (OMI) on the Aura platform; the Multi-angle Imaging Spectroradiometer (MISR) and Measurements Of Pollution In The Troposphere (MOPITT) on the Terra platform; the Moderate Resolution Imaging Spectroradiometer (MODIS) on both Aqua and Terra; Advanced Microwave Scanning Radiometer 2 (AMSR2) on the Global Change Observation Mission–Water series (GCOM-W; also called *Shizuku*, which means water in Japanese); and Visible–Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP) and Joint Polar Satellite System-1(JPSS-1) platforms. For more information, visit *https://earthdata.nasa.gov/earth-observation-data/near-real-time/about-lance*.

[2] Summaries of the previous LANCE workshops can be found in previous issues of *The Earth Observer* and at *https://earthdata.nasa.gov/earth-observation-data/near-real-time/about-lance#ed-lance-uwg*.

[3] To learn more, see "Summary of the Workshop on Time-Sensitive Applications of NASA Data" in the March-April 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 2**, pp. 19-22—*https://eospso.gsfc.nasa.gov/earthobserver/mar-apr-2017*].

[4] **UPDATE:** JPSS-1 successfully launched on November 19, 2017, and was renamed NOAA-20.

[5] LANCE requires that each element be responsible for: ingesting, processing, and distributing NRT data to end-users; integrating ESDIS Earthdata login (i.e., user registration), providing metadata to the Common Metadata Repository (CMR); providing imagery to the NASA's Global Imagery Browse Services (GIBS); providing system metrics to ESDIS Metric System; and providing end-user support. For more information, visit *https://wiki.earthdata.nasa.gov/display/LANCE/Requirements+Checklist+for+LANCE+Elements*.

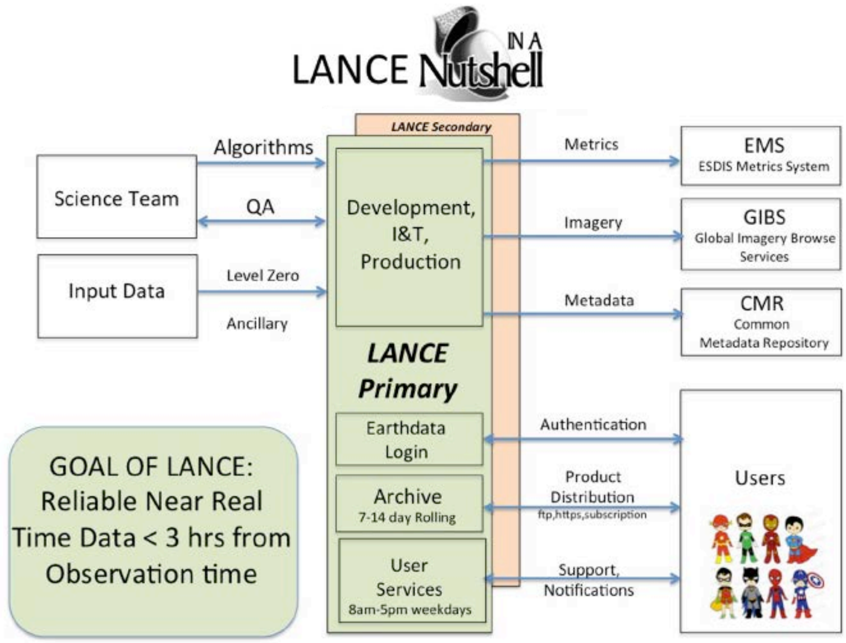

Figure 1. This chart summarizes the components of LANCE and how they interact with each other and with elements outside LANCE. **Image credit**: Karen Michael

Feedback from Programs that Use LANCE Data

LANCE data are used for a wide range of applications. The UWG heard reports from two programs that routinely use LANCE data, including suggestions on what might be done to make LANCE data more useful and more accessible.

Applied Remote Sensing Training (ARSET) Program

Ana Prados [University of Maryland, Baltimore County/GSFC], project manager for the Applied Remote Sensing Training (ARSET) program, said they routinely use data provided through LANCE, Worldview, and Fire Information for Resource Management System (FIRMS) for their training programs. ARSET is funded by the Applied Sciences Program of NASA's Earth Science Division (ESD) and offers satellite remote sensing training that builds skills to integrate NASA Earth Science data into an agency's decision-making activities. Training is offered in air quality, climate, disaster, health, land, water resources, and wildfire management, and reach several thousand people a year. Prados reported on results of surveys of those who received ARSET training; they indicate that people enjoy using online tools such as NASA's Worldview and FIRMS, and find these applications easy to use. From the groups sampled, she explained that flood products are the most popular. As part of the survey users are asked: What else can NASA do for you? The most common answers were: more training, tutorials, and exercises; improved spatial and temporal resolution; and more information on data uncertainty. To read a few particularly relevant feedback comments from users, see *User Feedback from ARSET* below.

User Feedback from ARSET

"...It is also true that there are many tools, sometimes many more than can be learned, so it would be great if there were a catalog or summary of all NASA tools and their most common applications, with examples..."

"I hope NASA continues making all its satellite data more easily accessible, from a single, central repository."

"Even though the contribution of NASA to the worldwide research is outstanding, a dedicated website which could gather the information of all products would be very helpful. This might be the 'starting' point to go and visit other dedicated websites. Thank you a lot for making the data publicly available."

"Keep providing great products with clear and concise documentation of how the products were created and their uncertainties."

Disaster Response Activities

Miguel Román [GSFC] presented information on behalf of **David Green** [NASA HQ, ASD—*Program Manager for Disasters*]. As part of his presentation, Román addressed how LANCE could be improved. He suggested LANCE could:

- focus on impacts (e.g., flood extent and infrastructure damage);
- build capacity to generate custom or experimental NRT products using multiple sources of data (e.g., VIIRS, Landsat/Sentinel-2,[6] Synthetic-Aperture Radar (SAR), and geographic information system (GIS) layers); and
- recognize and be responsive to the diversity of end users and their needs.

Román emphasized the need to report on data quality when providing data to operational organizations to avoid providing misleading information. **Ana Prados** noted that after a disaster, users often want a product or image quickly and rush to get something—anything!—without being aware of possible problems that could cause misinterpretation. Román suggested that the new motto for LANCE-NRT should be: *We'd rather be right than first.* **Chris Justice** suggested that ideally, the motto should be: *We'd rather be right—and first!*

[6] Each Sentinel mission is a constellation of two satellites. In order to fulfill revisit and coverage requirements, they carry a range of technologies, such as radar and multispectral imaging instruments for land, ocean, and atmospheric monitoring. For more information on each mission, see *http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4*. Subsequent references will be to specific Sentinel missions.

LANCE Updates and Metrics

This session began with **Diane Davies** [ESDIS—*LANCE Operations Manager*] presenting a brief overview of LANCE metrics. The ESDIS Metrics System (EMS) collects information on LANCE to accurately understand the amount of data archived and distributed, and other related information. It also tracks whether the LANCE is meeting the three-hour latency requirement. There are a growing number of registered users, and the LANCE elements are generally exceeding the latency requirement, as illustrated in **Figure 2**. Davies also said that FIRMS is being updated to give it a more modern look and feel. The beta version should be available in late November, and may be accessed at *https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms*.

After Davies' overview of LANCE metrics in general came a series of updates on products from specific missions.

Ed Masuoka [GSFC] gave an update on current MODIS products in LANCE. He said that MODIS Collection 6.1 (C6.1) was added in September to correct a number of issues in the Collection 6 (C6) Level-1B (L1B) data. The decision to create a new improved C6.1 was driven by the MODIS Atmosphere

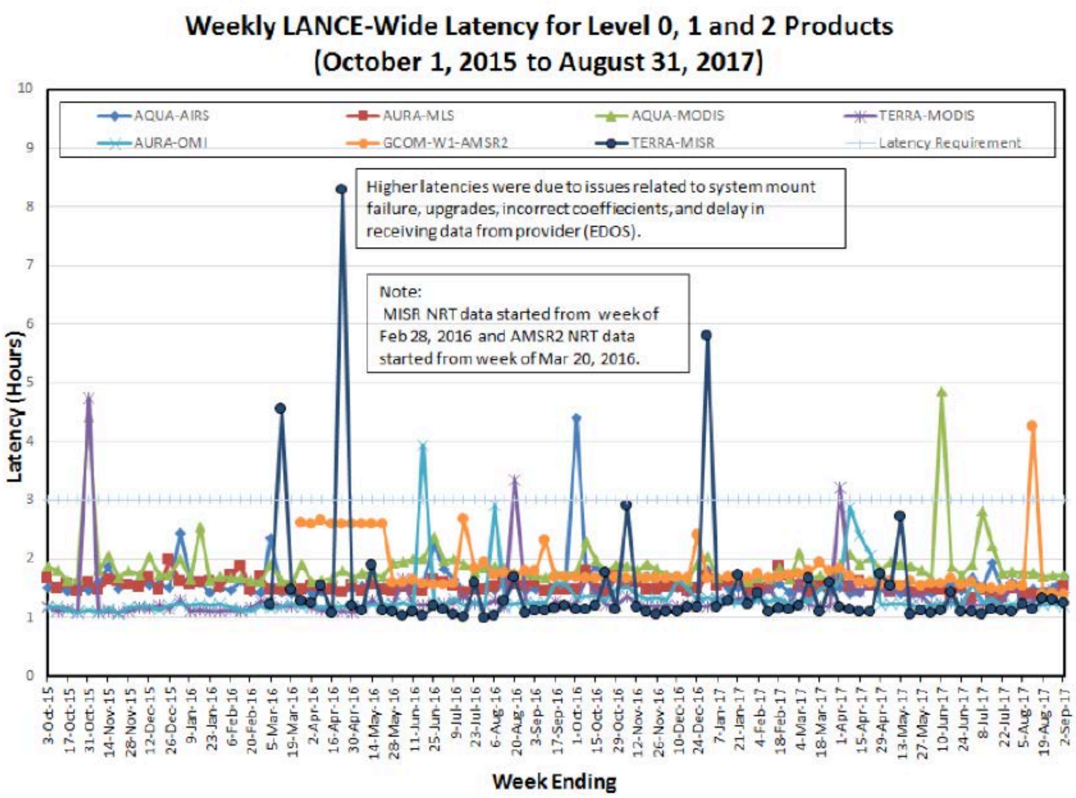

Figure 2. LANCE-wide latency metrics for Level-0, -1, and -2 products for October 1, 2015 – August 31, 2017. **Image credit:** ESDIS EMS

team to address a number of issues in the current C6 L1B data. These L1B issues had a negative impact in varying degrees in downstream MODIS Atmosphere Level-2 (L2) and Level-3 (L3) products. More information can be found at *https://modis-atmosphere.gsfc.nasa.gov/documentation/collection-61*. Masouka stressed that all MODIS L1 and Atmosphere product users are encouraged to switch over to C6.1.

Starting in November 2017, C6 Land processing stream will use the C6.1 L1B data as input, with no change to the land-science processing algorithms. Masuoka explained that they do not expect to see any significant impact to most land products from using upstream C6.1 as inputs except for some minor differences in Terra MODIS snow and sea-ice products because of differences in the Terra cloud mask. Therefore, C6 processing of NRT Terra- and Aqua-MODIS Land products will continue until sometime around the middle of 2018, when C6.1 processing of Land products will start.

Phil Durbin [GSFC/ADNET Systems, Inc.] gave an update on OMI LANCE products. The OMI Aerosol products were updated over the summer of 2017 to accommodate a new version of the algorithm. Imagery from the updated products are available in NASA's Global Imagery Browse Services (GIBS; *https://earthdata.nasa.gov/gibs*) and Worldview (*https://earthdata.nasa.gov/worldview*).

Sherry Harrison [University of Alabama, Huntsville] reported on the AMSR2 NRT products, which are generated using modified versions of the Advanced Microwave Sounding Radiometer for EOS (AMSR-E) standard product algorithms. These preliminary AMSR2 products will gradually be replaced with AMSR2 standard algorithms but still provided in NRT. Harrison announced that the first of these, the standard Land (Soil Moisture) algorithm has replaced the beta NRT algorithm.

Updates on Planned LANCE Enhancements and New Data Products

Since last year, NRT data from the MOPITT instrument has been added to LANCE and progress has been made adding additional products from MODIS, VIIRS, and the Ozone Mapping and Profiler Suite (OMPS).[7]

MOPITT

MOPITT has successfully become a LANCE element. **Dan Ziskin** [National Center for Atmospheric Research (NCAR)] explained that MOPITT NRT data can be downloaded from the NCAR Wyoming Supercomputing Center (*lance1.acom.ucar.edu*) or via the secondary server (*lance2.acom.ucar.edu*) at NCAR's Mesa Lab in Boulder, CO.

MODIS

Ed Masuoka described a new Land Surface Temperature (LST) Product [MxD21] from NASA/Jet Propulsion Laboratory (JPL) that uses data from the National Centers for Environmental Prediction (NCEP) Global Forecast System, rather than the Modern Era Retrospective-analysis for Research and Applications (MERRA)-2, which typically has a data latency of one month. This will be the second LST NRT product. There are no plans to make a VIIRS equivalent of the existing LST Product [MxD11], but there are plans to implement a VIIRS version of the new one, so introducing it now will provide continuity moving forward.[8]

Dan Slayback [GSFC/Science Systems and Applications, Inc. (SSAI)] provided an update on the MODIS NRT global flood product, which is being transitioned to LANCE. He explained the history of the product's development: The first (manually generated) flood products were produced by the Dartmouth Flood Observatory using MODIS Rapid Response Imagery. In 2010 the system was formalized into the MODIS Global NRT Flood Mapping system, run out of GSFC, with funding from NASA's Applied Sciences Program. In 2016 the LANCE UWG approved the transition of the global flood application to LANCE, and so it became the first applications product to be so transitioned. The transition is being funded by NASA's Applied Sciences Program which plans to support this effort through to the end of Fiscal Year 2018. The flood product likely will be running in LANCE by early 2018.

VIIRS

Ed Masouka discussed plans for incorporating VIIRS Land Products into LANCE. NRT3 (Primary) and NRT4 (Backup) servers are running operational VIIRS Collection 1 Product Generation Executables (PGEs), and generating LANCE VIIRS products, which include: Geolocation, Level-1B, L2 Fire [375 m (~1230 ft)], and L2 and L2G Land Surface Reflectance. All products are of the same science quality as the standard science V1 products produced by the Land Science Investigator-led Processing Systems (SIPS) and distributed by NASA's Distributed Active Archive Centers (DAACs). Additional products will be placed into NRT processing after the standard science products are available at the DAACs and NRT versions have been reviewed and approved by the respective principal investigators for each product.

[7] OMPS is onboard the Suomi NPP satellite and is also on the Joint Polar Satellite System-1 (JPSS-1), launched November 18, 2017. OMPS data will soon be supported by LANCE.

[8] NRT MOD21 and MYD21 are now available from *ftp://nrt3.modaps.eosdis.nasa.gov/allData/6* and *ftp://nrt4.modaps.eosdis.nasa.gov/allData/6*.

Jess Braun [University of Wisconsin, Madison] discussed the status of VIIRS Atmospheric Products as they relate to LANCE. Three VIIRS data products have been identified for NRT production: the Cloud Mask (day/night) product, which should be ready for distribution in December 2017; the Aerosol Dark Target (day) product, ready for distribution in March 2018; and the Aerosol Deep Blue product, also ready for distribution in March 2018.

Black Marble: VIIRS Nighttime Products

The VIIRS *Black Marble*,[9] or nighttime lights layer, is created using a sensing technique designed to capture low-light emissions under varying illumination conditions, and is displayed as a gray-scale image. A number of sources contribute to the Black Marble layer, including city lights, lightning, fishing-fleet navigation lights, gas flares, lava flows, and even auroras. **Miguel Román**, who leads the development of the Black Marble product, showed how NASA's Short-term Prediction Research and Transition Center (SPoRT) has been producing hand-crafted Black Marble products to highlight power outages in the wake of Hurricane Maria. Groups such as the National Guard and the Federal Emergency Management Agency used these products to help prioritize where to deploy resources. An automated NRT version of the product is expected to be available in LANCE by the end of 2017. The Black Marble Science PGE software status report as of October 2017 showed that six of the seven PGEs have been successfully integrated, tested, and baselined at the Land SIPS.

OMPS

Phil Durbin described how NRT products from OMPS are being processed and will soon be made available. The UWG accepted a recommendation to switch the OMPS sulfur dioxide (SO_2) algorithm from a linear-based approach to a principal component analysis (PCA) approach. The OMI Science Team has adopted the PCA approach for the LANCE OMI SO_2 product since it produces more accurate retrievals and is faster than the linear-fit algorithm. By adopting the PCA algorithm for the OMPS product, the UWG agreed that product continuity will be ensured and a better product will be produced.

There are no planned aerosol optical depth (AOD) or aerosol index (AI) products for OMPS since neither were selected as part of the 2014 NASA Research Opportunities in Space and Earth Science (ROSES) call[10] that solicited proposals to continue long-term climate records from EOS instruments using Suomi NPP instruments. The OMPS proposal to continue the long-term total ozone record (starting with Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) and Solar Backscatter Ultraviolet (SBUV) radiometer through to Aura OMI) using data from Suomi NPP OMPS was selected, while the proposal to continue the aerosol optical depth record from Aura OMI with data from Suomi NPP OMPS was not selected. However, **Mike Fromm** [U.S. Naval Research Laboratory (NRL)] mentioned that because of OMI's row anomaly,[11] there is interest in the LANCE user community for an OMPS AI product to continue the OMI AI LANCE product. **Colin Seftor** [GSFC/SSAI] and **Phil Durbin** took an action to write up what is required to produce AOD and AI OMPS products in NRT; he will submit the document to ESDIS.

ISS-LIS

Sherry Harrison described how NRT data are routinely produced from the International Space Station–Lighting Imaging Sensor (ISS- LIS). She asked the UWG to consider whether these data should be distributed through LANCE. The data will be made available through UAH, but the ISS-LIS Science Team believes that distributing the data through LANCE would make it easier for users to find them. However, because LIS-ISS is only a two-year mission, the Science Team requested a waiver to LANCE requirements to not implement a redundant system (although as UAH moves its data to the cloud over the next year, this may provide a second string).

Spotlight on NRT Applications

Four LANCE UWG members provided insights on how their organizations use LANCE NRT data, highlighting some of the practical benefits of using NASA's Earth science data, scientific knowledge, and technology. These reports are summarized in the **Table** on page 39.

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[9] Images of the Earth at night are referred to as NASA's Black Marble. Similarly, images of Earth during daylight hours are referred to as NASA's Blue Marble.

[10] The call was titled, "Suomi National Polar-orbiting Partnership (NPP) Science Team and Science Investigator-led Processing Systems for Earth System Data Records from Suomi NPP."

[11] This is a well-known anomaly on OMI. OMI's row anomaly was so named because it affects about half of the OMI swath (i.e., around half of its 60 rows across the swath). It is thought to have been caused when material outside of the instrument shifted to block a portion of the incoming light. This material also reflects light from outside of its field-of-view into the instrument. To learn more about the current state of OMI, see the "OMI Science Team Meeting Summary" on page 26 of this issue.

Table. Summary of Presentations on NRT Applications from LANCE UWG Members.

UWG Member [Affiliation]	Topic
Kim Richardson [NRL]	NRL Monterey's use of LANCE data: providing situational awareness to protect Department of Defense assets
Brad Zadovsky [MSFC, SPoRT]	NASA SPoRT's use of LANCE data for weather and disaster applications
Bob Brakenridge [University of Colorado]	Flood Observatory's use of LANCE data to create flood products
Brad Quayle [U.S. Forest Service]	Use of NRT satellite data in support of wildland fire management for the Continental U.S., Alaska, Hawaii, Puerto Rico, and Canada

NASA Disasters Program: ArcGIS Portal Overview

Dalia Kirschbaum [GSFC] gave an overview of the new NASA Earth Science Disasters Program portal (*https://maps.disasters.nasa.gov*). Hosted at the NASA Center for Climate Simulation at GSFC, NASA's Applied Sciences Disasters program provides funding for the portal, which is used to support activities in response to specific disasters. It will bring together relevant data and imagery layers specific to an event, including data products created specifically for an event. The rationale for the portal is that disaster managers need data in a GIS format to improve tactical and operational decision making, assist with rescue and response, and provide up-to-date situational awareness about a particular event. End-users will be able to bookmark the site, subscribe to receive updates, embed live information products into their own GIS systems, and access NRT automatic feeds. **Jessica Seepersand** [NASA HQ] oversees development of the portal. Data products from the Global Precipitation Measurement (GPM) mission, MODIS, and Sentinel-1 will be among the first available through the portal, including a NRT flood product. The portal will build on the work of LANCE by ingesting NRT products produced by LANCE and combining them with other relevant data sets and GIS layers. The portal will contain metadata that point users back to the original data sources.

Wrap-Up

Chris Justice concluded the meeting by thanking everyone for their participation and said the presentations highlighted the importance of low latency data for a range of applications. He noted that LANCE is likely to attain greater visibility within the Applied Sciences Program as more end-users are involved in responding to extreme events, and use the disasters portal. He said LANCE is essentially a data pipeline that provides NRT data and imagery to the science and applications communities. Until recently, LANCE has created NRT versions of science products generated by NASA's instrument science teams, but this pattern has begun to change: LANCE is currently transitioning two new applications products into LANCE (the NRT Global Flood Product and the NRT Black Marble product). In the future, the UWG will probably be asked to consider additional new applications products and multisource products. While this is not a new problem, it is getting bigger and requires consideration and commitment by the Applied Sciences Program as to how to fund the initial development and long-term maintenance of these products.

Justice noted that there is still a need to engage with new missions to encourage continued NRT data availability for operational decision makers. He reminded the group that this was a key recommendation from the NASA NRT workshop (September) last year: *Future solicitations and directed missions should evaluate data latency and the benefits and costs of providing NRT data vis-à-vis the benefit to operational decision makers.* Adding such an evaluation early on in the mission proposal review would help ensure that mission teams have an opportunity to explore the benefits of including low-latency data products and possibly accommodate NRT data without compromising a mission's primary science objectives. ■

Summary of the 2017 LCLUC-SARI International Science Meeting

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Garik Gutman, NASA Headquarters, ggutman@nasa.gov

Introduction

NASA LCLUC-SARI meeting participants in Chiang Mai, Thailand. **Photo credit:** NARIT team

South/Southeast Asian countries have the highest population growth rate worldwide and account for more than 25% of the global population. This population growth—together with rapid economic development—is leading to the conversion of forested areas to agriculture and agricultural areas to residential and urban uses, with significant impact on ecosystem services. Increased land cover and land-use changes in the region are impacting forest resources, biodiversity, regional climate, biogeochemical cycles, and water resources. To address these issues in the framework of NASA's Land Cover/Land Use Change (LCLUC) Program-funded South/Southeast Asia Research Initiative (SARI), an international science meeting was held in Chiang Mai, Thailand, July 17-19, 2017. The National Astronomical Research Institute of Thailand (NARIT), based in Chiang Mai, hosted the meeting.

The goal of the meeting was to review the availability, potential, and limitations of different satellite data sources and methodologies for land-use mapping, quantification, monitoring, and environmental impact in South/Southeast Asia. Overview presentations described research accomplishments and the current state of scientific information on these topics. The meeting included a poster session with 40 presentations. In total, 165 participants from 16 countries from Asia, Europe, and the U.S. attended the meeting. Scientists from other space agencies also attended, including representatives from the Japan Aerospace Exploration Agency (JAXA), the Space Technology Institute (of Vietnam) and Vietnam National Space Center (VNSC), the Geo-Informatics and Space Technology Development Agency (GISTDA) of Thailand, the International Centre for Integrated Mountain Development (ICIMOD) in Nepal, as well as representatives from international programs, including the Global Observation of Forest and Land Cover Dynamics (GOFC–GOLD) and Group on Earth Observations' (GEO) Global Agricultural Monitoring [GEOGLAM]. After the meeting, 95 early-career scientists from different countries participated in a three-day, hands-on training, focused on the use of remote sensing and geographic information systems (GIS) for LCLUC applications. The local hosts also organized a two-day field visit that gave meeting participants an opportunity to observe local land cover and land use changes in and around Inthanon National Park in Chiang Mai—see *Field Visit to Inthanon National Park* on page 41.

The meeting had the following objectives:

- to review regional and national science priorities, relating to LCLUC in the region;
- to review the causes and impacts of LCLUC specific to agriculture, forests, urban, and coastal ecosystems;
- to review greenhouse gases (GHGs) and aerosol sources, sinks, and impacts; and
- to strengthen the SARI activities.

Toward those ends, the agenda was organized around the following four themes:

- agricultural LCLUC;
- emission inventories and land-atmosphere interactions;
- urban LCLUC; and
- LCLUC and forestry.

Field Visit to Inthanon National Park Offers Opportunity to Observe Land Cover and Land Use Change in Thailand

The meeting hosts organized an optional two-day field visit to the area in and around Inthanon National Park to give participants an opportunity to see a specific example of how land cover and land-use change issues (e.g., impact of plantations on the land surface) were playing out in a specific case in Thailand. Along the way, participants could see examples of dense and intact cloud forests—see top photo—and other places where the forest has been converted to paddy fields—see bottom photo.

The high mountain cloud forests in Doi Inthanon, Chiang Mai, Northern Thailand, are immersed in fog and rain for much of the year. **Photo credit:** Krishna Vadrevu

Participants also visited the Doi Inthanon Royal Project Foundation (RPF), which is involved in improving the quality of life of local hill tribes through promoting sustainable agriculture, and conservation of forests and water resources. The RPF's activities began in 1969 with the encouragement from His Majesty, King Bhumibol Adulyadej. Since then, RPF activities expanded and currently there are 38 development centers spread across five provinces over the northern part of Thailand including Chiang Mai, Chiang Rai, Mae Hong Son, Lamphun, and Phayao.

These terraced rice fields are located in Pa Pong Pieng Village, northern Thailand, which is located at an elevation of 1022 m (~3353 ft). This is an example of where the forest has been cleared to create agricultural fields; both land cover and land use has changed. **Photo credit:** Krishna Vadrevu

Three panel discussions focused on emerging research questions in agricultural LCLUC, land-atmosphere interactions, and LCLUC in SARI countries. There was also a plenary discussion session that addressed SARI regional science, research, and capacity-building priorities. Meeting presentations are available at *http://lcluc.umd.edu/meetings/lcluc-sari-international-regional-science-meeting-southsoutheast-asia*.

Opening Remarks

The meeting began with welcoming remarks from the local host **Boonrucksar Soonthornthum** [National Astronomical Research Institute of Thailand (NARIT)—*Executive Director*], who stated that NARIT is enabling the development of an international collaborative research network, both regionally and globally, to develop and strengthen knowledge in atmospheric sciences useful for astronomy and to address local air pollution. LCLUC is the main driver of air pollution in Thailand; thus, the current meeting is of immense significance to build collaborations with the international researchers. In this vein, he noted that atmospheric science research at NARIT is being developed by procuring new instruments to address air pollution (discussed later). **Ronald Macatangay** [NARIT—*Atmospheric Science Lead*] welcomed participants and reemphasized that NARIT is strengthening air-pollution measurement capabilities and looking forward to engaging in collaborative research.

Chris Justice [University of Maryland, College Park (UMD), U.S.—*LCLUC Program Scientist*] also gave welcoming remarks, during which he stated that South/Southeast Asian countries are undergoing rapid changes in land cover and land use, and SARI meetings are useful for bringing U.S. and international scientists together to discuss the latest updates in these areas. **Toshimasa Ohara** [National Institute of Environmental Studies (NIES), Japan] remarked that air pollution in South/Southeast Asian countries is closely tied to land management, so the current meeting provides an important forum to link issues related to land-cover and land-use change in this region with atmospheric science.

Garik Gutman [NASA Headquarters—*LCLUC Program Manager*] provided an overview of NASA's LCLUC Program. He stated that over the last twenty years, the LCLUC Program has supported 267 research projects across many regions of the world—including SARI countries. He stated that the ultimate vision of this program is to develop the capability for periodic global inventories of land-cover and land-use change from space, to develop the scientific understanding and models necessary to simulate the processes taking place, and to evaluate the consequences of observed and predicted changes. Gutman stated that agricultural land use change is important in the SARI region and that agricultural monitoring has emerged as a key priority for the Group on Earth Observations (GEO) program. As crop assessments of both type and condition require nearly weekly data at spatial resolution of less than 50 m (~164 ft), combining data from the joint U.S. Geological Survey (USGS)–NASA Landsat missions and the European Space Agency's Copernicus Sentinel[1] missions can provide data at greater than five-day intervals. He added that in Southeast Asian countries of Myanmar, Cambodia, Vietnam, the Lao People's Democratic Republic (henceforth referred to as *Laos*), and Thailand, rubber and palm-oil plantations have been expanding due to rising prices. In South Asia, especially in Southern India, rice paddy-based farming is being replaced by shrimp farming, and mangrove forests are dwindling in Sundarbans, Bangladesh, and Halong Bay, Vietnam. NASA has funded four different LCLUC synthesis projects in the SARI region. Furthermore, NASA recently funded an interdisciplinary science project focusing on the Lower Mekong River Basin (in the SARI region). More details about the program can be found at *http://lcluc.umd.edu*.

Krishna Vadrevu [NASA's Marshall Space Flight Center—*SARI Lead*] presented the meeting's objectives—summarized in the Introduction. He added that international collaborations are key to building strong SARI–LCLUC research activities. Vadrevu also noted that most SARI meetings and training sessions are funded by several international and regional partners and that SARI is planning to organize additional events with regional partners in the future.

Agricultural LCLUC

Chris Justice presented information on the GEOGLAM initiative, which was first endorsed by the Group of Twenty (G20) Agriculture Ministers in June 2011. GEOGLAM promotes and supports reliable, accurate, timely, and sustained national crop-monitoring information and yield forecasts. He described the development of the UMD agricultural monitoring activities, which started in 2005 with efforts by NASA and the U.S. Department of Agriculture to transition crop analysis from AVHRR[2] to MODIS.[3] At the global scale, GEOGLAM is providing monthly Crop Monitor bulletins (*https://cropmonitor.org*) in partnership with the Agricultural Market Information System, which is hosted at the United Nations' Food and Agriculture Organization (UN FAO), located in Rome, Italy. One of the best examples of GEOGLAM regional coordination is the Asia-Rice project (*http://www.asia-rice.org*) which, as its name implies, focuses on rice-crop estimates and monitoring in Asia. The target products include rice crop area estimates and maps, crop calendars, crop damage assessment, agrometeorological information products, production estimates, and yield forecasting.

Kei Oyoshi [JAXA] presented updates on JAXA's mission and agricultural applications on behalf of the Asia-Rice team, which is comprised of stakeholders involved in rice crop estimation and monitoring for the GEOGLAM initiative. Data from the Japanese Advanced Land Observing Satellite-2 (ALOS-2) are being used to map rice extent in Asia; the International Asian Harvest mOnitoring system for Rice (INAHOR) rice-mapping software has been developed to estimate rice-planted area and specific growth stage using ALOS-2 data. INAHOR has been successfully demonstrated through the Space Applications for Environment (SAFE) and Asia-Pacific Regional Space Agency Forum (APRSAF) projects. With regard to future missions, Oyoshi reported that the Global Change Observation Mission-Climate (GCOM-C) spacecraft is scheduled for launch on December 23, 2017. GCOM consists of two satellite series, the GCOM-Water (GCOM-W) and GCOM-C. GCOM-W, with the Advanced Microwave Sounding Radiometer 2 (AMSR)

[1] Each Sentinel mission is a constellation of two satellites. In order to fulfill revisit and coverage requirements, they carry a range of technologies, such as radar and multispectral imaging instruments for land, ocean, and atmospheric monitoring. For more information on each mission, see *http://www.esa.int/Our_Activities/Observing_the_Earth/ Copernicus/Overview4*. Subsequent references will be to specific Sentinel missions.

[2] AVHRR stands for Advanced Very High Resolution Radiometer (AVHRR), which flies on a series of National Oceanic and Atmospheric Administration (NOAA) Polar-orbiting Operational Environmental Satellites (POES).

[3] MODIS stands for Moderate Resolution Imaging Spectroradiometer (MODIS), which flies on NASA's Terra and Aqua platforms.

onboard, was launched in 2012, and is part of the international A-Train[4] constellation; it measures precipitation, water vapor amounts, wind velocity above the ocean, sea water temperature, water levels on land areas, and snow depths. GCOM-C carries the Second-generation GLobal Imager (SGLI), which will conduct surface and atmospheric measurements related to the carbon cycle and radiation budget, such as horizontal distribution of clouds and aerosols, ocean color, vegetation, and snow and ice. He also mentioned the upcoming Greenhouse Gases Observing Satellite 2 (GOSAT-2), which is a continuation of the GOSAT-1 mission to measure carbon dioxide (CO_2). GOSAT-2 is scheduled for launch in 2018. Oyoshi also reported that Japan is a partner on the upcoming EarthCARE[5] mission, a sun-synchronous satellite that measures the three-dimensional structure of clouds and aerosols; it is also scheduled for launch in 2018. Plans are also underway to launch the Advanced Land Observing Satellite-3 (ALOS-3), an optical mission, and ALOS-4, a radar satellite, in the 2020 and 2020-2021 timeframes, respectively.

Nguyen Lam-Dao [Space Technology Application Center, Vietnam] discussed the rice mapping and monitoring efforts in the Mekong River Delta, Vietnam. Through its participation in the Asia–Pacific Regional Space Agency Forum's (APRSAF) Space Applications for Environment (SAFE) [2013-2017], and GeoRice [2015-2017] projects, data from the Italian Space Agency's COnstellation of small Satellites for the Mediterranean basin Observation (COSMO)-SkyMed, the Canadian Space Ageny's RADARSAT-2, ALOS-2, and Sentinel-1, are being used for rice monitoring. Results suggest that during 2016 rice area was reduced due to water shortages and intrusion of saline water. In addition, two additional projects funded by the state, VNRice and Catch Mekong, are developing rice area maps and crop calendars that include yield estimates. He stated that a national synthetic aperture radar (SAR) satellite, Lotussat-1, is scheduled for launch in 2019, and a Lotussat-2 mission planned for 2022.

Mir Matin [ICIMOD, Nepal] highlighted that ICIMOD is developing operational mapping and monitoring of different crops to support food-security-related decisions in the Himalaya region. In Afghanistan, an annual wheat-area-mapping algorithm is being implemented that integrates phenological characteristics from Sentinel-1 and -2 data using the Google Earth Engine. Also, a Nepali operational agricultural monitoring system is being developed.

[4] "A-Train" is a nickname for the *Afternoon Constellation,* which is the name given to a group of several NASA and international Earth-observing satellites that closely follow one after another along the same orbital "track." To learn more, visit *https://atrain.gsfc.nasa.gov*.

[5] EarthCARE stands for Earth Clouds, Aerosol, and Radiaton Explorer, and is a joint European–Japanese partnership being developed as an Earth Explorers mission under ESA's Living Planet Programme.

Emission Inventories and Land Atmospheric Interactions

Toshimasa Ohara [NIES] presented information on the historical analysis and inverse modeling of air pollutant emissions in Asia. The spatially gridded, Regional Emission inventory in ASia (REAS) has been developed for 1950–2015, covering east, southeast, and south Asian countries at a spatial resolution of 0.25° × 0.25°, monthly, for target species. He stated that emissions of all air pollutants in Asia increased significantly during the six decades of the study, and that sulfur dioxide (SO_2) and oxides of nitrogen (NO_x) seem to have reached their ceiling. There is high uncertainty in the data, especially regarding agricultural emissions and evaporative nonmethane volatile organic carbon (NMVOC) emissions. REAS is now being improved through integrating top-down, inverse modeling, chemical transport modeling, and bottom-up emissions data to reduce these uncertainties.

Eric Vermote [NASA's Goddard Space Flight Center] described the atmospheric correction for Landsat 8 and Sentinel-2 data, and validation of land aerosol and surface reflectance products. He stated that Landsat 8/ Operational Land Imager (OLI) and Sentinel-2 surface-reflectance data are largely based on the MODIS Collection 6 algorithm. Vermote also reported that Version 3 of the Landsat 8 surface reflectance product is available, having been validated satisfactorily; and that Version 2 of the Sentinel-2 atmospheric correction algorithm has been successfully implemented.

George Lin [National Central University, Taiwan] explained that the Seven SouthEast Asian Studies (7-SEAS) project[6] is investigating impacts of aerosol particles on weather and the total southeast Asian environment. This campaign has been active since 2007; phase three is currently underway, running from 2016 to 2018. The Spring 2018 campaign will focus on plume-transport to Taiwan from pollution sources on the mainland including Thailand, Vietnam, China, and Hong Kong. The Fall 2018 campaign will collaborate with NASA flight missions scheduled to take place in Southeast Asia.

Ronald Macatangay [NARIT] explained that NARIT-procured aerosol samplers provide fast, reliable, high-resolution aerosol measurements (e.g., total solid particles, particulate matter), from ground level to the troposphere. Plans are underway to establish the Total

[6] 7-SEAS has been established to characterize aerosol-meteorological interactions from Java through the Malay Peninsula and Southeast Asia to Taiwan. Learn more at *https://7-seas.gsfc.nasa.gov*.

Carbon Column Observing Network (TCCON)[7] for measuring CO_2, airborne campaigns to measure pollutants, and to integrate satellite remote sensing data with these measurements to better characterize air pollution in Thailand.

Tsuneo Matsunaga [NIES] showcased the CO_2 and methane (CH_4) emission trends from GOSAT. Results suggest that the East China/Japan region is the largest CO_2 emitter in Asia, and that South and Southeastern Asian regions are almost CO_2 neutral. He then focused on CH_4, showing that East China/Japan and India are important emitters and that models and inventories may underestimate the amplitude of seasonal variations. He mentioned that GOSAT-2, which as mentioned earlier is scheduled for launch in 2018, will have more enhanced Earth-observation capabilities than GOSAT. Matsunga also informed the participants that GOSAT Level-4A CO_2 and CH_4 monthly regional net flux products are now available.

Narisara Thongboonchoo [King Mongkut's Institute of Technology, Thailand] stated that in Northern Thailand, the industrial sector released more NO_x emissions than biomass burning, whereas biomass burning released more carbon monoxide (CO) and particulate matter (PM) than industrial activities. Her presentation emphasized the efforts she and her colleagues are making to integrate satellite and ground-based methods to reduce uncertainties in emission inventories.

Somporn Chantara [Chiang Mai University, Thailand] described the results from open burning combustion chamber experiments. Rice straw, maize residue, leaf litter from mixed deciduous forests, and leaf litter from dipterocarp (mainly lowland rainforest) trees were burnt under controlled conditions. Results suggest that 20-to-25 times more CO_2 was emitted under these conditions than CO. She mentioned that volume aerosol samplers were erected at Mae Hia, Chiang Mai, and Na Noi (all in Nan Province in Thailand) to monitor and analyze ambient $PM_{2.5}$,[8] chemical composition, and toxicity in Northern Thailand.

Paul Griffiths [Cambridge University, U.K.] showcased the results on ozone (O_3) from the United Kingdom Chemistry and Aerosols (UKCA) model. He stated that O_3 is produced mostly in the Northern Hemisphere and lost in the tropics. Land-use change impacts O_3, as loss or gain of vegetation cover can impact O_3 deposition and removal.

[7] To learn more, see "Integrating Carbon from the Ground Up" in the July–August 2014 issue of *The Earth Observer* [**Volume 26, Issue 4**, pp. 13-17—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/JulyAug_2014_color508.pdf*].

[8] $PM_{2.5}$ refers to particulate matter (PM) with a diameter of 2.5 µm or less. (For comparison, 2.5 µm is about 3% of the diameter of a human hair.) These are also known as *fine particles,* as opposed to PM_{10} (with diameter 10 µm or less), which are called *coarse particles.*

Two presentations focused on economic development, urbanization, and emissions. **Prakhar Misra** [University of Tokyo, Japan] stated that air quality in several megacities of India is deteriorating, with industries and construction activities as the major culprits. **Tatsuya Hanaoka** [NIES] summarized the emission reduction strategies specific to CH_4 from the waste sector. He stated that China and Indonesia are the largest emitters of GHGs followed by India, Japan, and Vietnam. Of the different socioeconomic variables, gross domestic product per capita could explain most of the variation in municipal solid waste-related emissions.

Urban LCLUC

The presentations in this session focused on sustainable urban planning in several SARI countries.

Douglas Webster [Arizona State University, U.S.] stated that transportation, thermal power plants, and industries are the three leading sources of GHG emissions in several SARI countries. He mentioned that having green vegetation in urban areas is important for GHG reduction. He then described how an urban plan is driven primarily by housing needs, but should take into consideration vegetation surface characteristics and transportation needs.

Peilei Fan [MSU] showed how urbanization in Vietnam has been driven by economic development (including the inflow of the foreign direct investment), and has worsened local environmental conditions. Meanwhile, in Yangon, Myanmar, productive farmlands are being converted to urban areas.

Mastura Mahmud [Universiti Kebangsaan, Malaysia] highlighted how different cities in Malaysia contribute to local and regional CO_2 emissions. She also described how uncontrolled urbanization in Kuala Lumpur caused green space to decline by 43% between 1990 and 2010.

LCLUC and Forestry

This session included several forestry case studies and showcased tools and techniques useful for forest-based LCLUC studies.

Kenlo Nasahara [University of Tsukuba, Japan] summarized the high-resolution land-cover mapping projects that are ongoing at the JAXA-Earth Observation Research Center (EORC). Multi-temporal ALOS-Advanced Visible and Near Infrared Radiometer type 2 (AVNIR2) high-level products at 10-m (~33-ft) spatial resolution were used to produce a land-cover map for the period 2006-2011, with overall accuracy of 80% (verified from ground-truth observations). ALOS-AVNIR2 data were also used to assess the impacts of the 2011 nuclear power plant disaster in Fukushima. A global-scale forest/nonforest map from 2007 through 2010, 2015, and 2016 utilizing ALOS Phased Array type L-band Synthetic Aperture Radar (PALSAR)-1 and -2 at 25-m (~82-ft) spatial resolution is also generated. He mentioned that Japan Earth Resources Satellite (JERS)-PALSAR data have been used for high-resolution land-cover mapping in northern Vietnam and agriculture mapping in eastern Thailand. Further, the ALOS-3 optical imaging and ALOS-4 radar missions (previously described) will each add additional land cover and land use change monitoring capabilities.

David Saah [University of San Francisco, U.S.] described the regional land-cover monitoring system (RLCMS) developed as a part of SERVIR's[9] Mekong River Delta-area activities (*https://www.nasa.gov/mission_pages/servir/mekong.html*). RLCMS was developed based on a needs assessment involving government agencies, non-governmental organizations, and research institutions in the Mekong region. He explained that RLCMS has a modular system architecture and runs in the Google Earth Engine to produce useful land-cover maps. For the reference data collection, another tool— "Collect Earth Online"—has been developed (*http://ceo.sig-gis.com/about*). Nearly 20,000 observations on land use and land cover have already been collected using the tool.

Chengquan Huang [UMD] showcased the utility of the Vegetation Change Tracker (VCT) algorithm for forest-disturbance mapping using Landsat data. He stated that the VCT algorithm outputs have been validated across the U.S. and that the North American Forest Disturbance data product that depicts a 25-year history of U.S. forest disturbances is distributed through the Oak Ridge National Laboratory's Distributed Active Archive Center (ORNL DAAC) (*https://daac.ornl.gov/NACP/guides/NAFD-NEX_Forest_Disturbance.html)*.

Krishna Vadrevu showcased the potential of Sentinel-1A data for estimating above-ground biomass in different forests in India. He explained that variations in tree density could explain most of the variation in the SAR backscatter signal (they are significantly more correlated than basal area and above ground biomass) and that an exponential model fit well for tree density and above-ground biomass data for both VV and VH[10] backscatter.

Atul Jain [University of Illinois, U.S.] presented details on improving satellite-derived forest-cover dynamics in South and Southeast Asia. He mentioned that differences in satellite-based forest-cover estimates can be attributed to different algorithms, limited ground data used for training and validation, variation in forest cover definitions, and postprocessing methodologies. He emphasized the need to integrate climate and topography information in LCLUC algorithms for better classification accuracy.

Stephen Leisz [Colorado State University, U.S.] explained that the East-West Economic Corridor (EWEC) was envisioned as a project that would upgrade the transportation infrastructure and simplify border controls along a corridor stretching from Da Nang, Vietnam, through Laos, into northeast Thailand, and into Myanmar, ending in Mawlamyine. The goal of the effort is to improve the connectivity within the corridor and to reduce poverty in the area. He then went on to discuss some of the specific urban and rural land cover and land-use challenges specific to drivers in the EWEC countries, which are complicated to address. For example, tree cover seems to be increasing in some locations and decreasing in others. Urban encroachment on rural areas is happening across three countries, with Thailand being most advanced and Laos the least.

Birendra Bajracharya [ICIMOD] stated that LCLUC activities in ICIMOD are driven by application needs in Nepal. Sample projects undertaken by ICIMOD include quantifying LCLUC dynamics in Kangchenjunga, estimating soil-erosion dynamics in the Koshi River Basin, assessing flood damage in Bangladesh, and SERVIR-funded decadal LCLUC analysis in Hindu Kush Himalayas. A *mountain geoportal* for dissemination of data and applications has been developed. ICIMOD recently signed a memorandum of understanding with Global Forest Watch, and is collaborating with USGS SilvaCarbon (*https://egsc.usgs.gov/silvacarbon/node/30.html*) and UMD team on LCLUC studies.

Rabin Raj Niraula [HELVETAS Swiss Intercooperation, Nepal] showed that in Nepal, deforestation due to agricultural expansion is most common; however, afforestation programs and community-based forest-management activities also assisted forest regrowth in several regions. He mentioned that the rate of annual deforestation decreased from 1.7% per

[9] SERVIR is not an acronym; it's a Spanish word that means "to serve." It is a joint venture between NASA and the U.S. Agency for International Development (USAID) that provides state-of-the-art, satellite-based Earth monitoring, imaging and mapping data, geospatial information, predictive models, and science applications to help improve environmental decision-making among developing nations. The lower Mekong River Basin in Southeast Asia is one of their "hubs," along with the Hindu–Kush region of the Himalayas; they also have two other "hubs" in Africa.

[10] VV and VH stand for vertical transmit and vertical receive and vertical transmit and horizontal receive, respectively. These are polarization channels for a radar system. To learn more about polarization in radar systems, visit *http://www.nrcan.gc.ca/node/9567*.

year during the 1990s to 0.18% per year in 2014, and implied that sustainable forestry management involving local people is the best way to mitigate deforestation.

Faizul Bari [Forest Department, Pakistan] stated that in Pakistan, 5.5% of the country is occupied by forests, which are rapidly degrading due to heavy demand for timber and fuel wood, overgrazing, conversion to agriculture, construction of Eucalyptus and populus plantations, housing development, and infrastructure development. He stressed the need for regular mapping and monitoring of LCLUC, proper land-use planning and governance, and increased awareness for sustainable development.

Soe Myint [Arizona State University, U.S] stated that over the span of 14 years (2000-2014), a total of 215,680 ha of mangrove forest was lost in Myanmar, with an annual mean deforestation rate of 2.21%.Also, a projected net change rate of 1% of mangrove loss per year will result in a mean annual change in Net Primary Productivity rate of three metric tons of carbon per year per square kilometer. He used these results to emphasize that conserving mangrove vegetation is of high importance in Myanmar.

Mani Murali [National Institute of Oceanography] stated that in the region near the delta of the Mahanadi River in India, sandy areas, fallow lands, and mudflats are decreasing as the area around the river is converted to croplands and built-up areas. Human intervention in the hinterlands is affecting the coastal systems, and decreased sediment flux, cyclones, and floods are the main causes of erosion in the region.

Three presentations focused on LCLUC specific to plantations. **Louis Lebel** [Chiang Mai University, Thailand] mentioned that socioeconomic development as reflected in Gini[11] household income trajectories has been uneven in Thailand. Boom and bust development (e.g., the buildup of rubber and palm-oil production in recent years, leading to an abundance of these items, and a consequent decline in prices) has impacted landscapes and livelihoods. Scenario studies suggest that continued expansion of rubber and fruit trees at the expense of forests will impact watershed services.

Jefferson Fox [East–West Center, U.S.] stated that national policies and variables relating to global markets (i.e., supply, demand, and price) have been driving rubber production expansion in Southeast Asia. Due to such expansion, indigenous households have been losing access to land and are forced to relocate to marginal lands. Labor is becoming scarce and will eventually become more problematic than access to land. Fox emphasized the need for more integrated studies to address LCLUC, their drivers, and socioeconomic impacts.

Randolph Wynne [Virginia Polytechnic Institute, U.S.] stated that plantation forestry is rapidly expanding in Asia and that understanding the drivers and ramifications of the presence of these new trees outside forest landscapes is vital. Specific to Andhra Pradesh in southern India, the drivers of plantation expansion include availability of marginal lands, absentee landlords, low maintenance, and productive pest-resistant species.

Discussion Sessions

Across the three sessions, panel members and participants were asked to identify important research priorities. In addition, a plenary discussion session was organized on SARI regional science, research, and capacity-building priorities. The **Table** [below] summarizes the discussions from each of the three panels and captures the most pressing issues and research priorities.

[11] The *Gini coefficient* or *Gini ratio* (when it is normalized) is the most widely used single-summary number for judging the wealth distribution of a particular nation; in essence, it gives a measure of economic equality.

Table. Summary of Topics Raised During Discussion Sessions

Topic Area	Specific Topics Discussed
Agricultural LCLUC	• Addressing urban agricultural land encroachment • Combating pollution related to biomass burning of agricultural residues • Developing operational tools for mapping of crops • Developing seasonal weather forecasts to allow farmers to better manage crop calendars • Creating operational tools to monitor agricultural productivity and diseases including early forecasting • Forging international cooperation on free and open sharing of data useful for agricultural applications • Capacity building and training activities on the use of new technologies

continued on next page

Table. Summary of Topics Raised During Discussion Sessions. (cont.)

Topic Area	Specific Topics Discussed
Land-Atmosphere Interactions	• Addressing transboundary air pollution problems • Mitigating pollution through development of sustainable technologies • Mitigating biomass burning pollution • Understanding regional and global linkages in land-atmospheric interactions • Developing high-resolution emission inventories integrating top-down and bottom-up inventories • Conducting missions and source apportionment studies • Understanding aerosol-cloud-radiation interactions • Improving accessibility to tools for atmospheric research studies • Capacity building and training relating to atmospheric modeling • Open data sharing mechanisms
LCLUC	• Connecting land cover with land use • Assessing land-use and land-cover changes related to water quality degradation and alleviated cross-border water conflicts • Improving understanding of impact of land-cover and land-use change impacts on the larger system—e.g., some afforestation in Nepal leads to reduced irrigation for agriculture • Reducing GHG emissions from land-cover change especially in peatlands and restoring traditional forests • Deciding how to best communicate results and research findings to share with stakeholders and interested communities, generally

Conclusion

The meeting's presentations and discussion sessions focused on synergies among various approaches and provided recommendations on how to improve the role of Earth observations, ground data, and modeling techniques to improve our understanding of LCLUC in SARI countries. Participants identified the need to develop regionally consistent LCLUC products, and all participants agreed on the need to develop mission-effective strategies to transition from research to operational products to help inform policy. Common issues that surfaced during the discussions included the need to strengthen research, capacity building, and training activities in South/Southeast Asian countries. Overall, the meeting was highly successful in addressing LCLUC issues in South/Southeast Asia.

Request for papers: As a part of the meeting outputs, papers are being solicited on LCLUC in South/Southeast Asia, to be part of a Special Issue of the International Journal of Digital Earth. All researchers working on LCLUC in South/Southeast Asia are invited to submit articles at *http://explore.tandfonline.com/cfp/est/ijde/si-4*. Plese email **Krishna Vadrevu** (*krishna.p.vadrevu@nasa.gov*) for additional details.

in the news

New Insights From OCO-2 Showcased in *Science*

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

High-resolution satellite data from NASA's Orbiting Carbon Observatory-2 (OCO-2) are revealing the subtle ways that carbon links everything on Earth—the ocean, land, atmosphere, terrestrial ecosystems, and human activities. Using the first 2.5 years of OCO-2 data, scientists have recently published a special collection of five papers in the journal *Science* that demonstrates the breadth of this research. In addition to showing how drought and heat in tropical forests affected global carbon dioxide levels during the 2015-16 El Niño, other results from these papers focus on ocean carbon release and absorption, urban emissions, and a new way to study photosynthesis. A final paper by **Annmarie Eldering** [NASA/Jet Propulsion Laboratory (JPL)—*OCO-2 Deputy Project Scientist*] and colleagues gives an overview of the state of OCO-2 science.

Emissions from Individual Cities and Volcanoes Visible from Space

More than 70% of carbon dioxide (CO_2) emissions from human activities comes from cities, but because the gas mixes rapidly into the atmosphere, urban emissions are challenging to isolate and analyze. **Florian Schwandner** [JPL] and colleagues used OCO-2 observations to detect how CO_2 emissions vary around individual cities—the first time this has been done with data collected from space in just a few minutes. Over Los Angeles and the surrounding area, they were able to detect differences as small as 1% of total atmospheric CO_2 concentrations within the air column below the satellite.

The OCO-2 measurements across Los Angeles were detailed enough to capture differences in concentrations within the city resulting from localized sources. They also tracked diminishing CO_2 concentrations as the spacecraft passed from over the crowded city to the suburbs and out to the sparsely populated desert to the north—see **Figure**.

OCO-2's orbit also allowed it to observe significant CO_2 signals from isolated plumes of three volcanoes on the Pacific island nation of Vanuatu. Data from one orbit track directly downwind of Mt. Yasur, which has been erupting persistently since at least the 1700s, yielded a narrow string of CO_2 that was about 3.4 parts per million higher than background levels—consistent with emissions of 41.6 kilotons of CO_2 a day. This is a valuable quantification of volcanic emissions, which are small compared to the average human emissions of about 100,000 kilotons per day.

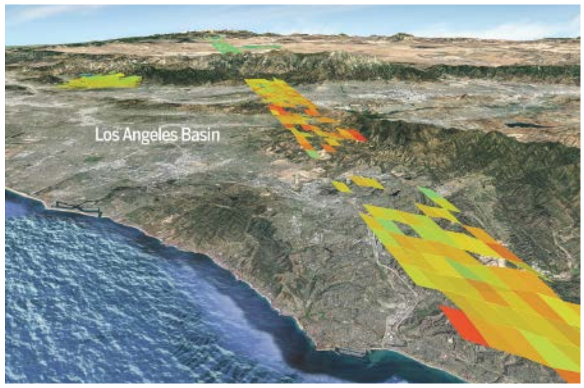

Figure. The *Science* special collection of OCO-2-based papers gives an unprecedented view from space of how CO_2 emissions vary within individual cities such as Los Angeles and its surroundings, shown here. Concentrations vary from more than 400 parts per million (black) over the city, foreground, to the high 300s (light gray) over the desert, background. **Credits:** NASA/JPL-Caltech/Google Earth

El Niño Suppressed Tropical Ocean's Release of Carbon

Abhishek Chatterjee [NASA's Goddard Space Flight Center] and colleagues studied how the big 2015-16 El Niño affected CO_2 over the tropical Pacific Ocean.

This ocean region is usually a source of CO_2 to the atmosphere. As part of global ocean circulation, cold, CO_2-rich water wells up to the surface in this region, and the extra CO_2 outgasses to the atmosphere. Because El Niño events suppress this upwelling, scientists have conjectured that it reduces the ocean's CO_2 emissions and therefore causes a slowdown in the growth rate of atmospheric CO_2 concentrations. However, until OCO-2, there haven't been adequate atmospheric observations over the remote tropical Pacific to confirm this theory.

OCO-2 data show that in the first few months of the 2015-16 El Niño, the rate of CO_2 released from the tropical Pacific to the atmosphere decreased by between 26 and 54%. That translates to a short-term reduction of 0.4 to 0.5 parts per million in atmospheric concentration, or close to 0.1% of total atmospheric CO_2.

A change of 0.1% in CO_2 may not sound like much, but consider that it occurred over a region in the Pacific Ocean about the size of the entire continent of Australia. This reduction in CO_2 emissions for a few months was strong enough that it could be observed by OCO-2 and the National Oceanic and Atmospheric Administration's Tropical Pacific Observing System of buoys, which directly measure CO_2 concentrations at the surface of the ocean. The record uptick in atmospheric CO_2 that occurred in 2015 and 2016 would have been even greater without this decrease in tropical Pacific Ocean emissions.

With OCO-2, scientists can observe these tiny changes for the first time, a first step toward understanding the sensitivity of the carbon cycle to climate variations on a scale of years to decades.

A New Way to Measure Photosynthesis

Besides CO_2, OCO-2's high-resolution spectrometers can observe solar-induced fluorescence (SIF). This radiation, emitted by chlorophyll molecules in plants, indicates that photosynthesis is occurring. SIF provides valuable insight into global photosynthesis because it captures photosynthesis not only during the growing season, but also its slowdown, for example, over evergreen forests in winter, when trees maintain chlorophyll but stop absorbing CO_2 from the atmosphere.

Ying Sun [Cornell University] and colleagues report on OCO-2's unique SIF measurements, which provide a much higher spatial resolution than any previous system. The improved resolution enabled the scientists to perform the first-ever validation of SIF from concurrent airborne observations.

OCO-2's smaller image "footprint" on Earth allowed the researchers to do a more direct comparison of the satellite measurements with ground-based measurements of flows of CO_2 between plants and the air. They found a consistent relationship between SIF and CO_2 uptake in plants across different types of ecosystems. This finding sets the direction for in-depth studies that may further illuminate the relationship between SIF and global photosynthesis.

OCO-2 Level-2, Build 8 Data Now Publicly Available

The Orbiting Carbon Observatory-2 (OCO-2) has released the latest version of the Level-1B (L1B) and Level-2 (L2) data products, containing estimates of the column-averaged carbon dioxide (CO_2) dry air mole fraction (XCO_2), solar-induced chlorophyll fluorescence (SIF), and other geophysical quantities retrieved from OCO-2 observations. This version of the L1B and L2 products is Build 8.0 and has been processed with an updated version of the OCO-2 L1 and L2 algorithms.

Some key features of the Build 8.0 products:

- Significant updates to the L1B radiometric calibration, improving the time dependence of the radiometric corrections (especially in the A-band), and removal of a small, time-dependent, scattered-light signal (referred to as ZLO).
- Updated gas-absorption cross-section tables and an improved land-surface reflectance bidirectional reflection model.
- The L2 algorithm now solves for stratospheric aerosol optical depths, which has substantially reduced the XCO_2 errors over the ocean in the Southern Hemisphere.
- Improvements to prescreeners that increased the amount of data and latitudinal coverage.

Both forward and retrospective versions of the Build 8.0 L1B and L2 products are routinely being delivered to the Goddard Earth Sciences Data and Information Services Center (GES DISC). The forward product, designated V8, uses information based on extrapolations of calibration data that were collected over the past 10 days for dark exposures or the past 3.43 days for throughput degradation. These V8 products, which span the time interval from November 9, 2017, to the present, are usually delivered to the GES DISC within one week of acquisition. They are generally reliable—except when the instrument experiences a significant change in its thermal environment that is outside of the training range used to derive the extrapolated calibration data. The retrospective L1B and L2 products, designated V8r, use interpolated calibration data and are therefore expected to be more reliable than the forward products. The V8r products span the entire mission (September 6, 2014, through the present) and are typically delivered to the GES DISC in one-month blocks, starting about five-to-six weeks after acquisition. The OCO-2 team recommends that the V8r product be used in applications where high accuracy is needed.

OCO-2 L2 V8r products are also available as "Lite" data products. These Lite data products are grouped into daily files and provide both uncorrected and bias-corrected XCO2 values, together with a reduced number of ancillary data fields. Another improvement over previous version is that the "warn levels" have been upgraded.

As for the previous data release, Build 7 (B7), the full and "Lite" data products are available at the NASA/Jet Propulsion Laboratory's CO_2 Virtual Science Environment site (*https://co2.jpl.nasa.gov*) and at the GES DISC site (*https://disc.gsfc.nasa.gov/uui/datasets?keywords=oco2*).

To learn more, visit: *https://docserver.gesdisc.eosdis.nasa.gov/public/project/OCO/OCO-2_DQ_Statement.pdf.*

China's Sulfur Dioxide Emissions Drop, India's Grow Over Last Decade

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

A new study by researchers at NASA's Goddard Space Flight Cener (GSFC) and the University of Maryland indicates that India may be the world's top sulfur dioxide (SO_2) emitter.[1]

SO_2 is an air pollutant that causes acid rain, haze, and many health-related problems. It is produced predominantly when coal is burned to generate electricity.

[1] The study was published in the journal *Scientific Reports* on November 9, 2017. To read the paper, visit *www.nature.com/articles/s41598-017-14639-8*.

Although China and India remain the world's largest consumers of coal, the new research found that China's SO_2 emissions fell by 75% since 2007—see **Figure 1**—while India's emissions increased by 50%—see **Figure 2**. The results suggest that India is becoming—if it is not already—the world's top SO_2 emitter.

"The rapid decrease of SO_2 emissions in China far exceeds expectations and projections," said first author **Can Li** [University of Maryland, College Park (UMD), Earth System Science Interdisciplinary Center, and GSFC—*Associate Research Scientist*]. "This

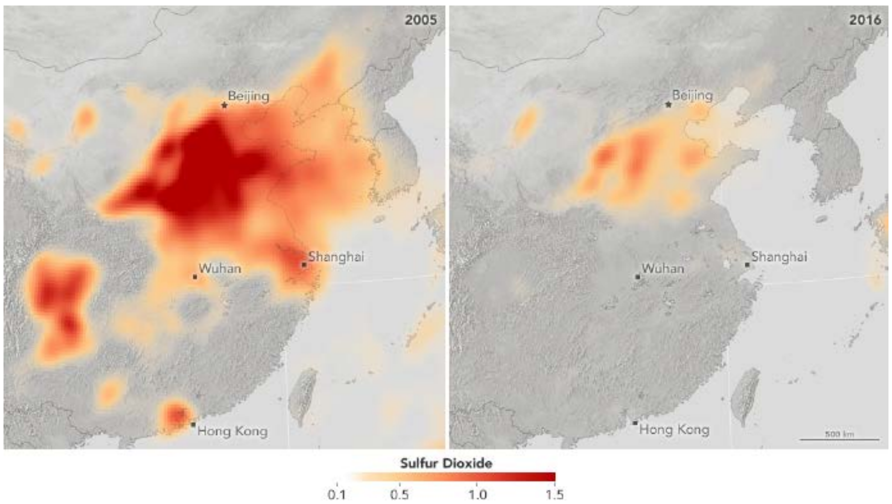

Figure 1. SO_2 concentrations for China have decreased significantly between 2005 and 2016. The values here are yearly averages of sulfur dioxide concentrations over India and China in 2005 and 2016. **Image credit**: NASA's Earth Observatory/ Jesse Allen

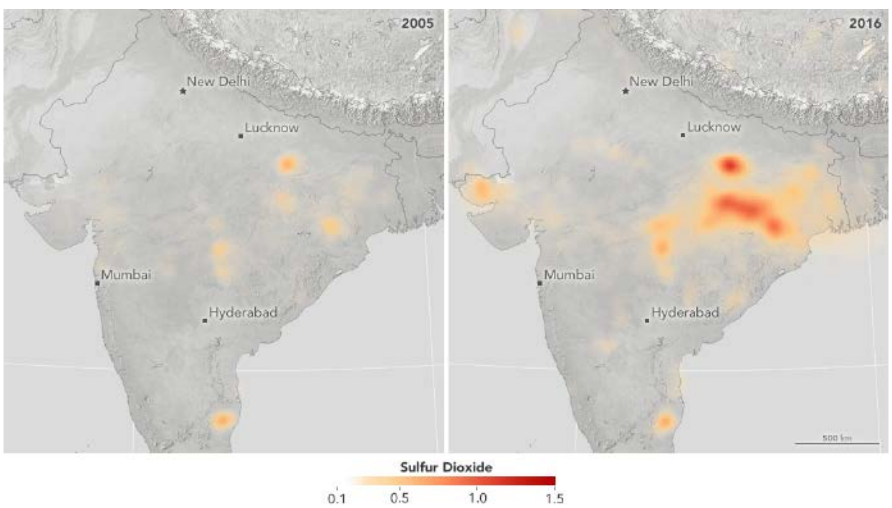

Figure 2. SO_2 concentrations over India have increased significantly between 2005 and 2016. The values here are yearly averages of sulfur dioxide concentrations over India and China in 2005 and 2016. (The study focused on changes since 2007.) **Image credit**: NASA's Earth Observatory/ Jesse Allen

suggests that China is implementing SO_2 controls beyond what climate modelers have taken into account."

China and India are the world's top consumers of coal, which typically contains up to 3% sulfur. Most of the two countries' SO_2 emissions come from coal-fired power plants and coal-burning factories. In particular, Beijing suffers from severe haze problems because of the many coal-burning factories and power plants located nearby and upwind.

Starting in the early 2000s, China began implementing policies such as fining polluters, setting emission reduction goals, and lowering emissions limits. According to the results of the current study, these efforts are paying off.

"SO_2 levels in China declined dramatically even though coal usage increased by approximately 50% and electricity generation [more than doubled]," explained Li. "This suggests that much of the reduction is coming from controlling emissions."

Despite China's 75% drop in SO_2 emissions, recent work by other scientists has shown that the country's air quality remains poor and continues to cause significant health problems. This may be because SO_2 contributes only some 10 to 20% of the air particles that cause haze, according to Li.

"If China wants to bring blue skies back to Beijing, the country needs to also control other air pollutants," Li said.

By contrast, India's SO_2 emissions increased by 50% over the past decade. The country opened its largest coal-fired power plant in 2012, and has yet to implement emission controls like China.

"Right now, India's increased SO_2 emissions are not causing as many health or haze problems as they do in China because the largest emission sources are not in the most densely populated area of India," Li said. "However, as demand for electricity grows in India, the impact may worsen."

To generate an accurate profile of emissions over India and China for the current study, the researchers combined emissions data generated by two different methods.

First, the researchers collected estimated emission amounts from inventories of the number of factories, power plants, automobiles, and other contributors to SO_2 emissions. These inventories, while important data sources, are often incomplete, outdated, or otherwise inaccurate in developing countries. They also cannot account for changing conditions or unforeseen changes in policy.

The researchers' second data source was the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite, which detects a variety of atmospheric pollutants, including SO_2. While OMI can collect up-to-date information and spot emission sources missing from the inventories, it can only detect relatively large emission sources. In addition, clouds or other atmospheric conditions can interfere with its measurements.

To overcome these challenges, Li and his colleagues collaborated with researchers from Environment and Climate Change Canada to develop better algorithms to quantify emissions based on OMI data. In addition, study co-authors **Russell Dickerson** and **Zhanqing Li** [both at UMD, Department of Atmospheric and Oceanic Sciences—*Professors*], used a weather aircraft to measure the concentrations of SO_2 and other air pollutants over one of the most polluted regions in China. These measurements were used to confirm that the upwind coal power plants were efficiently scrubbing SO_2 from their exhaust stacks.

By combining the OMI and inventory data, the researchers generated a more accurate estimate than comes from using either data source alone. Previously published studies, which relied on inventory data and published policies, projected that China's SO_2 emissions would not fall to current levels until 2030 at the earliest.

"Those studies did not reflect the true situation on the ground," said Li, who is also a member of the U.S. OMI Science Team. "Our study highlights the importance of using satellite measurements to study air quality, especially in regions where conditions may change rapidly and unexpectedly."

Li hopes the current study's results can be used to improve climate and atmospheric models by providing more accurate input data. ■

NASA's Living Planet Campaign

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Life. It's the one thing that, to the best of our knowledge, makes Earth unique among the thousands of other planets we've discovered. Since 1997, NASA satellites have continuously and globally observed all plant life at the surface of the land and ocean. During the week of November 13-17, 2017, NASA shared several stories and videos, on its website and via social media, about how this view of life from space furthers knowledge of our home planet and the search for life on other worlds. Summaries of and links to three of those articles are provided here.

The Changing Colors of Our Living Planet. NASA's satellites can see our living Earth breathe. For 20 years, NASA has continuously observed not just the physical properties of our planet, but also the ebb and flow of life at and near its surface. This space-based view of life allows scientists to monitor the health of crops, forests, and fisheries around the globe. But the space agency's scientists have also discovered long-term changes across continents and ocean basins. As NASA begins its third decade of global ocean and land measurements, these discoveries point to important questions about how ecosystems will respond to a changing climate and broad-scale changes in human interactions with the land. The article referenced here broadly traces the key developments in the history of our life-observing capabilities generally, tracing the story from Gemini and Apollo astronauts' photos to present-day observations. To learn more, visit *https://www.nasa.gov/feature/goddard/2017/the-changing-colors-of-our-living-planet*.

From Microscopic to Multicellular: Six Stories of Life that NASA Sees from Space. NASA's satellite-derived data have become a powerful tool to augment scientists' understanding of how life waxes and wanes on our planet. The global and continuous observing capabilities of satellites complement focused, ground-based observations, and are useful for studying changes in animal habitats over time, tracking disease outbreaks, monitoring forests, and even aided the discovery of a new species. While far from a comprehensive list of NASA's efforts, the visual stories of bacteria, plants, land animals, sea creatures, and birds summarized in this article give a sense of what the view from space can reveal. They include:

- Monitoring the Single-Celled Powerhouses of the Sea;
- Predicting Cholera Bacteria Outbreaks;
- Viewing Life on Land;
- Tracking Bird Populations;
- Parsing Out Plant Life; and
- Studying Life Under the Sea—see **Figure**.

Each of the six areas addressed in the article provide additional links to more information on the specific topics. To view the article, visit *https://www.nasa.gov/feature/goddard/2017/six-stories-of-life-that-nasa-sees-from-space*.

Figure. A thicket of coral as observed by scientists off Heron Island, Australia, during the COral Reef Airborne Laboratory (CORAL) field campaign on the Great Barrier Reef in October 2016. CORAL is using the compact, lightweight, airborne Portable Remote Imaging SpectroMeter (PRISM), developed at the NASA/Jet Propulsion Laboratory, which is compatible with a wide range of piloted and unpiloted aerial vehicle (UAV) platforms. PRISM collects data on key marine health indicators and helps scientists better understand how reef ecosystems respond to changing environmental conditions. **Image credit**: CORAL/Stacy Peltier

Our Living Planet Shapes the Search for Life Beyond Earth. In 1992, two scientists discovered the first planet around another star, an *exoplanet*. As of November 2017, scientists have confirmed more than 3500 exoplanets in more than 2700 star systems. **Anthony del Genio** [NASA's Goddard Institute for Space Studies] heads up a NASA interdisciplinary initiative to search for life on other worlds. With his Earth-science background, this leads to an obvious question: *Why would a scientist who has dedicated his life to studying Earth now head up the effort to find life "out there," among the stars?* In short, it's because what we've learned about Earth is essential to providing clues to scientists searching for life on other worlds about where they should focus their search. To learn more, visit *https://www.nasa.gov/feature/jpl/our-living-planet-shapes-the-search-for-life-beyond-earth*. ■

NASA Earth Science in the News

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Which Melting Glacier Threatens Your City the Most? NASA Tool Can Tell You, November 21, *space.com*. Melting ice affects sea level rise differently depending on where it happens, according to a new model scientists at NASA/Jet Propulsion Laboratory are using to study the changing climate. The tool will help predict how the regional ice melt will affect coastal cities. Sea levels have already begun rising as ice melts and the ocean heats up and expands. Although these effects are mostly evenly spread across the globe, regional changes can create local differences, NASA officials said in a statement. This has direct ramifications for 293 port cities, the data for which are included in the agency's new, free, interactive data visualization and simulation tool, available at *http://vesl.jpl.nasa.gov/research/sea-level/slr-gfm*.

From Space, 2017's Devastating Hurricanes Look Hypnotic, November 20, *nationalgeographic.com*. The 2017 hurricane season has been rife with superlatives: by all accounts, it was one of the most catastrophic, rainiest, and busiest we've seen in modern history. Hurricane Harvey dumped an unprecedented amount of rain on Houston, TX, in August; Irma had some of the strongest winds ever documented in the Atlantic; and Ophelia triggered bizarre weather phenomena in Western Europe. Based on news reports and citizen-provided images, it's easy to see the environmental damage left in the wake of these destructive hurricanes, but changing atmospheric currents that cause these hurricanes are harder to visualize. A new simulation published by NASA shows how these changes in the atmosphere can be observed by following the path of aerosol particles—tiny particles that float in the atmosphere—see **Figure 1**.

*__Earth "Breathes" in Amazing Time-Lapse Video from Space,__ November 20, *livescience.com*. NASA's satellites have monitored Earth from space for decades; for the past 20 years (since the launch of the Sea-viewing Wide Field-of-view Sensor, or SeaWiFS, in 1997) they been able to track the pulse of life in seasonal patterns as heat moves around the planet, sea ice grows and shrinks, and vegetation blooms and recedes on the continents and oceans. And now, data gathered by a fleet of satellites circling Earth since 1997 have been visualized as a breathtaking time-lapse video of our dynamic planet, capturing the most complete view to date of biology on a global scale, spanning two decades.

During warm months in each hemisphere, sea-ice cover near the poles declines and the lush green colors of emerging plant life spread in undulating waves over land, as more plants take up carbon dioxide and produce oxygen. In the ocean, microscopic phytoplankton swirl to form growing and shrinking cloud-like structure,

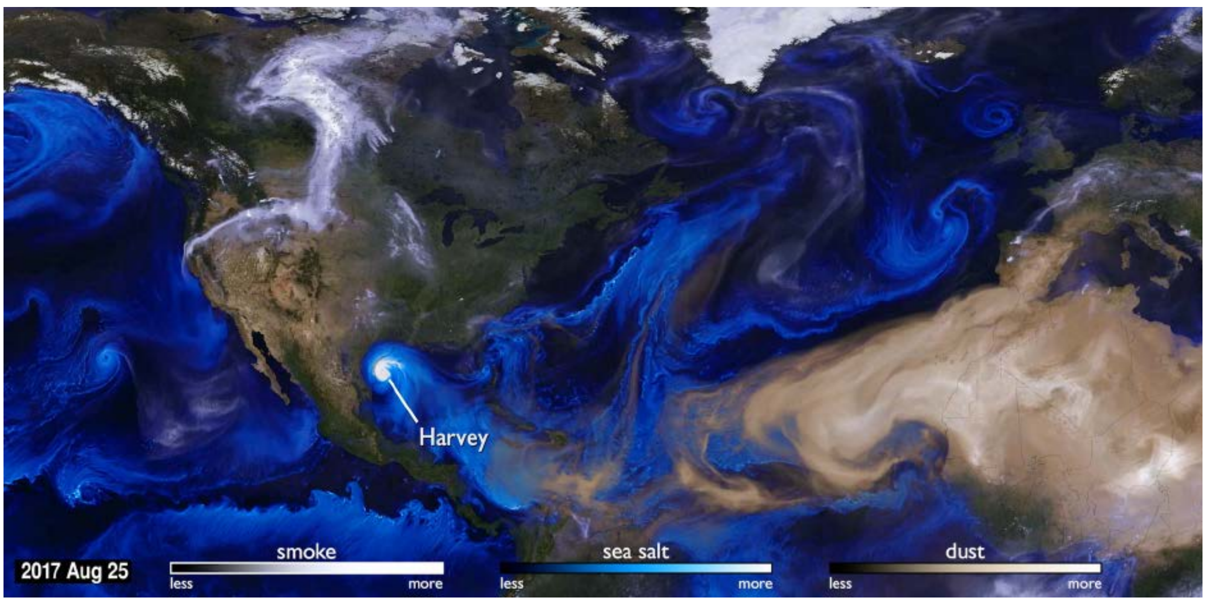

Figure 1. This image from a NASA visualization uses data from NASA satellites combined with mathematical models in a computer simulation to show how tiny aerosol particles such as smoke, dust, and sea salt are transported across the globe. Sea salt that has evaporated from the ocean swirls inside of Hurricane Harvey. During the same time, large fires in the Pacific Northwest released smoke into the atmosphere. The full visualization is available at *https://www.youtube.com/watch?v=h1eRp0EGOmE*. **Image credit:** NASA

similarly following seasonal cycles of growth and death that are visible as subtle color changes in the water. "That's the Earth—it is breathing every single day, changing with the seasons, responding to the sun, to the changing winds, ocean currents, and temperatures," said **Gene Carl Feldman** [NASA's Goddard Space Flight Center (GSFC)—*Oceanographer*] in a statement.

These Close-Up Images from NASA Show One of the Largest Icebergs Ever to Split Off from Antarctica, November 15, *washingtonpost.com*. NASA scientists have captured close-up images of a behemoth of an iceberg that detached from one of the largest floating ice shelves in Antarctica in July. The iceberg—known as A-68 and which is close to the size of Delaware—is one of the largest in recorded history to split off from Antarctica; it consists of almost four times as much ice as the melting ice sheet of Greenland loses in a year. "I was shocked, because we flew over the iceberg itself and it looks like it's still part of the ice shelf, in terms of how large it is and the surface texture," said **Nathan Kurtz** [GSFC—*Operation IceBridge Scientist*], who traveled to Antarctica near the end of October to get a closer look at the iceberg. "To see it fully detached, to see this massive block of ice floating out there [as shown in **Figure 2]** was pretty shocking," he said. Satellite images in July first showed the 2200-mi^2 (~5698-km^2) iceberg calving and floating away from the Larsen C ice shelf. Scientists had been anticipating that the iceberg would break from the larger ice shelf, and in recent months watched the progress of a crack extending more than 100 mi (~161 km).

Figure 2. This photo taken on October 31, 2017, during an Operation IceBridge flight, shows the edge of the Larsen C Ice Shelf with the western edge of iceberg A-68 in the distance. **Photo credit:** NASA

"Mantle Plume" Nearly as Hot as Yellowstone Supervolcano Is Melting Antarctic Ice Sheet, November 8, *usatoday.com*. Antarctica is getting a little hot under the collar. A recent study found that just under the frozen wasteland of the world's coldest continent are some seriously hot rocks, which are helping to melt its ice sheet and create lakes and rivers. How hot? Try 1800° F (~982° C). The heat produced by the scorching hot rocks—officially known as a *mantle plume*—was measured at 150 mW/m^2. That's not far from the heat produced under Yellowstone National Park, which is measured at about 200 mW/m^2. The study is among the first to say that a mantle plume exists under Marie Byrd Land, a portion of West Antarctica. Study lead author **Helene Seroussi** [NASA/Jet Propulsion Laboratory] thought it was "crazy" that it would be there: "I didn't see how we could have that amount of heat and still have ice on top of it," she said. The goal of the study was to figure out how the ice sheet was able to stay frozen with such a warm mantle plume underneath, and to determine the amount of heat provided by the plume to the base of the ice sheet. Although the heat source isn't a new or increasing threat to the West Antarctic ice sheet, it could help explain why the ice sheet collapsed rapidly some 11,000 years ago and why it's so unstable today, Seroussi said. She added that understanding the sources and future of the meltwater under West Antarctica is important for estimating the rate at which ice may be lost to the ocean in the future.

The Hole in the Ozone Layer Is at Its Smallest in Nearly Three Decades, November 6, *seeker.com*. Although phasing out the chemicals that caused the ozone hole has led to gradual decrease in its areal coverage, natural variability in the climate has also played a role. Higher temperatures over Antarctica this year shrank the hole in the ozone layer to the smallest it's been since 1988. The ozone hole is a depletion of ozone gas (O_3) in the stratosphere above Antarctica. The three-oxygen molecule is toxic at ground level, but high in the atmosphere it is beneficial, as it prevents dangerous ultraviolet rays from reaching Earth's surface. In 1985 scientists first detected the hole in the ozone layer and realized it was being caused by manmade chlorine- and bromine-containing compounds, often found in chlorofluorocarbons (CFCs), earlier used as refrigerants. In 1987 the Montreal Protocol initiated the phase-out of these chemicals. As they gradually leave the atmosphere the ozone hole will heal, and scientists expect it to return to 1980s size by 2070. Natural variability affects this healing on a year-by-year basis, however. "The Antarctic ozone hole was exceptionally weak this year," **Paul Newman** [NASA's Goddard Space Flight Center—*Chief Scientist*], said in a statement. "This is what we would expect to see given the weather conditions in the Antarctic stratosphere [this year]."

*See News Story in this issue.

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

EOS Science Calendar

January 23–26, 2018
ABovE Science Team Meeting, Seattle, WA.
https://above.nasa.gov/meetings.html

March 19–23, 2018
2018 Sun-Climate Symposium,
Lake Arrowhead, CA.
http://lasp.colorado.edu/home/sorce/news-events/meetings/2018-scs

May 15–17, 2018
CERES Science Team Meeting
Hampton, VA.

June 4–6, 2018
ASTER Science Team Meeting,
Tokyo, Japan.

Global Change Calendar

January 7–11, 2018
AMS 98th Annual Meeting, Austin, TX.
https://annual.ametsoc.org/2018

February 11–16, 2018
Ocean Sciences Meeting, Portland, OR.
http://osm.agu.org/2018

April 8–13, 2018
European Geosciences Union (EGU) General Assembly, Vienna, Austria.
https://www.egu2018.eu

Undefined Acronyms Used in Editorial and Table of Contents

AGU	American Geophysical Union
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CERES	Clouds and the Earth's Radiant Energy System
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
GFZ	German Research Centre for Geosciences
GLOBE	Global Learning and Observation to Benefit the Environment
GOES-16	Geostationary Operational Environmental Satellite-16
JPL	NASA/Jet Propulsion Laboratory
KSC	NASA's Kennedy Space Center
LANCE	Land, Atmosphere Near real-time Capability for EOS
LCLUC-SARI	Land Cover/Land Use Change South/Southeast Asia Research Initiative
OCO-2	Orbiting Carbon Observatory-2
SAGE III	Stratospheric Aerosol and Gas Experiment III
Suomi NPP	Suomi National Polar-orbiting Partnership
TROPICS	Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

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