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Editor's Corner
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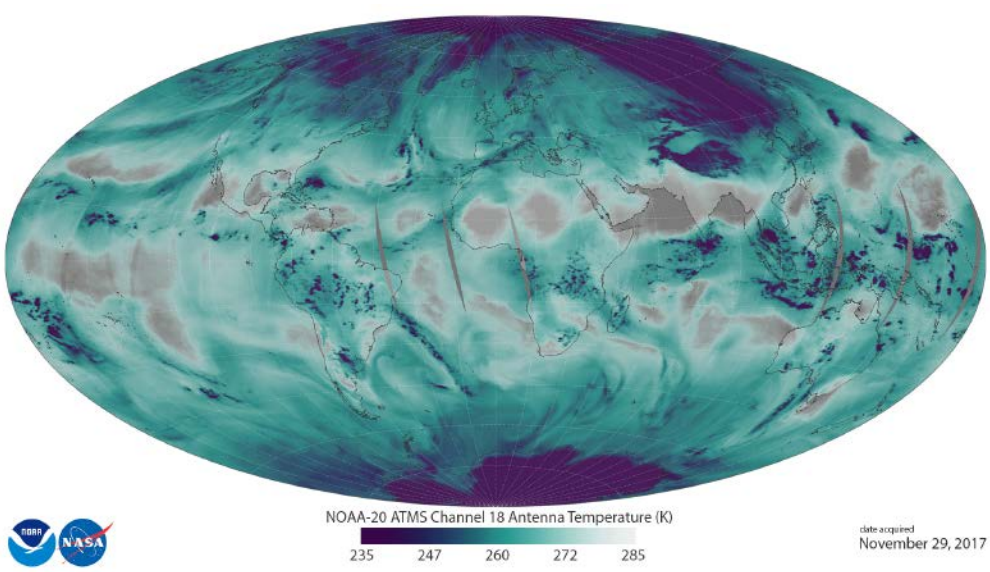
The year 2017 is ending with a flourish of activity for NASA Earth Science.

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*.

continued on page 2



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

www.nasa.gov

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**.

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.

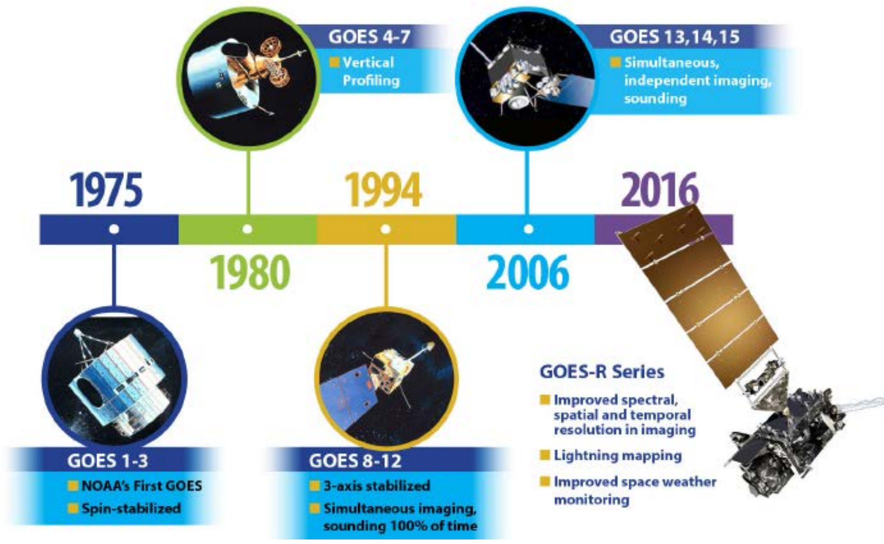

Figure 1. The GOES series has gone through evolutionary development with improvements in both the spacecraft and instruments. Further information on the series can be found at *http://www.goes-r.gov/mission/history.html*. **Image credit:** NOAA/NESDIS

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.

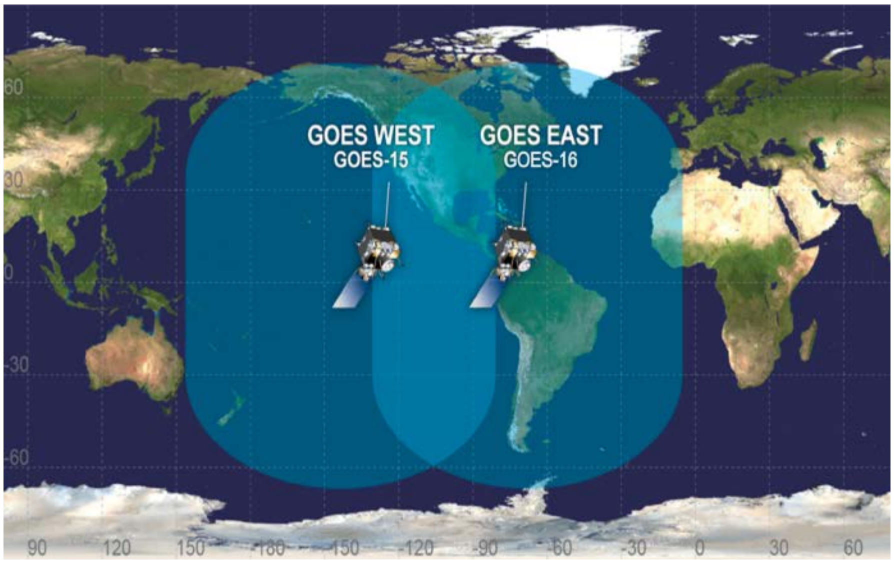

Figure 2. The GOES satellites operate from two primary locations: GOES East (GOES-16) is located at 75° W longitude and provides most of the U.S. weather information, and GOES West (GOES-15) is located at 135° W longitude. The observing latitude range for both satellites is between 68° N and S. Once 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.

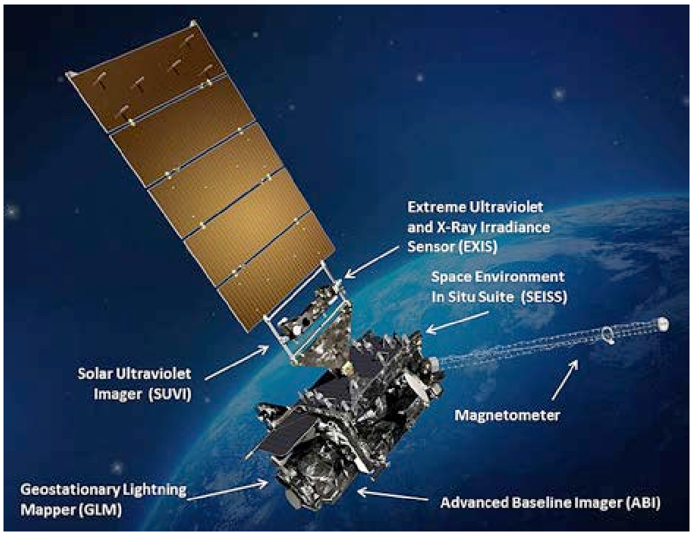

Figure 3. Location of the instruments on the GOES-R series of satellites. **Image credit:** Lockheed Martin

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*.

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.

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

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]

[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 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.

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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*.

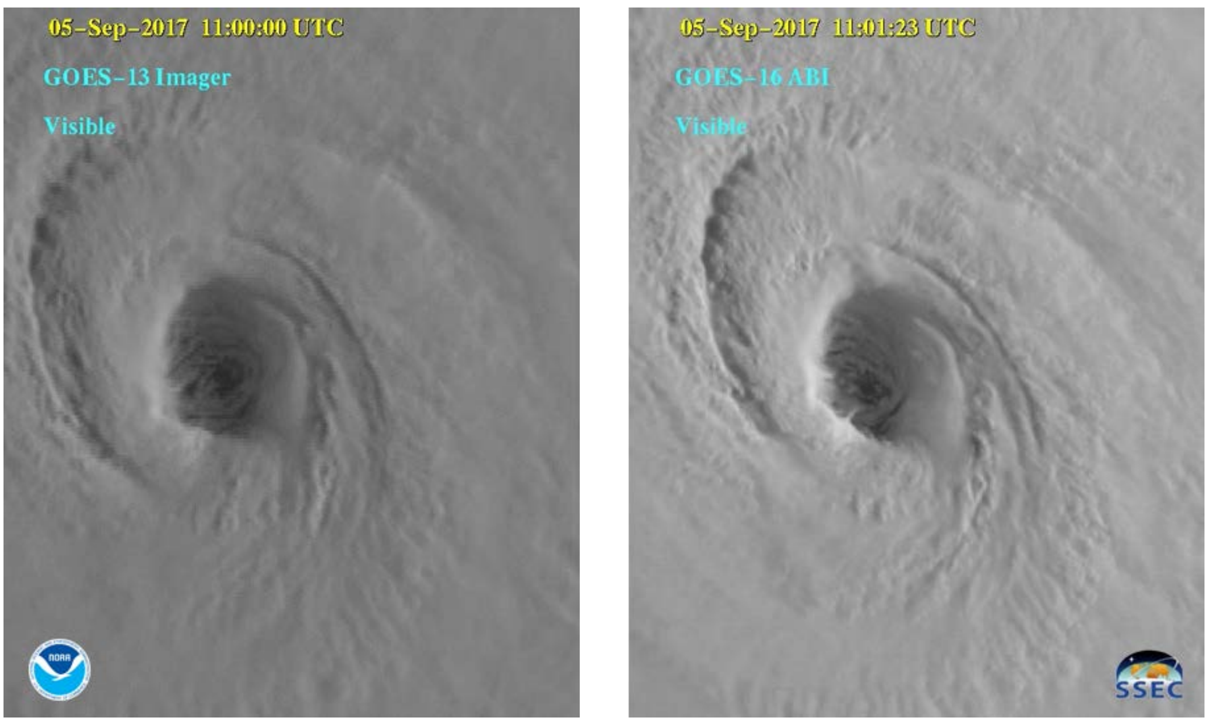

Figure 4. This figure demonstrates the increased spatial resolution of satellite data for Hurricane Irma from GOES-13 [*left*] and GOES-16 [*right*]. On previous GOES missions these high-resolution images were not routine, but with GOES-16's advanced capabilities, these images are now operational. **Image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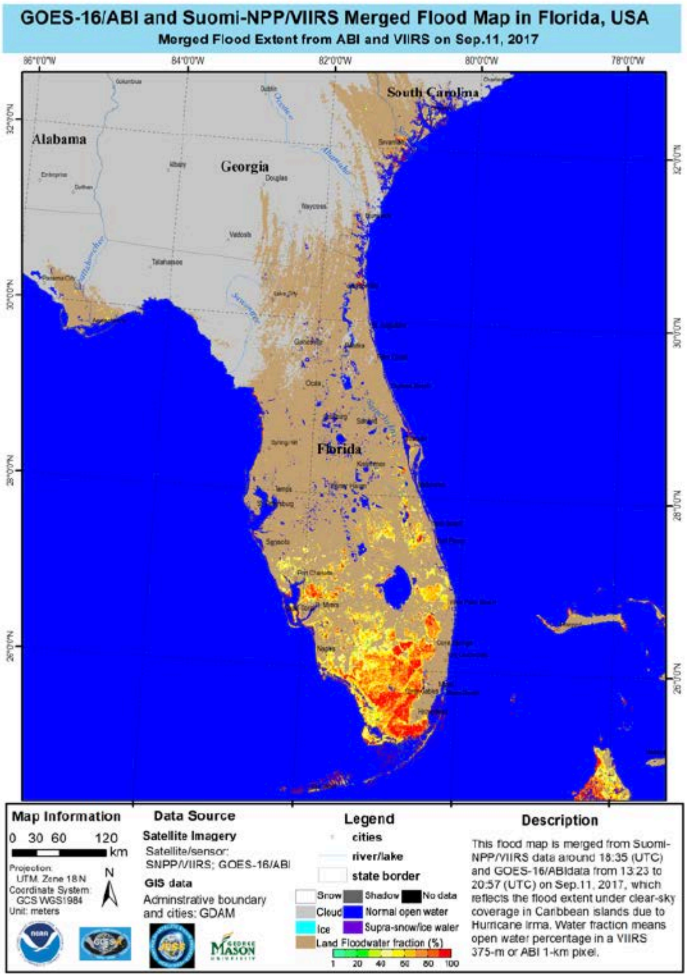

Figure 5. This flood map is merged from Suomi NPP VIIRS data around 1835 UTC and GOES-16 ABI data from 1323 to 2057 UTC on September 11, 2017. The map reflects the flood extent under clear-sky coverage in Florida due to Hurricane Irma. **Image credit:** George Mason University

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.

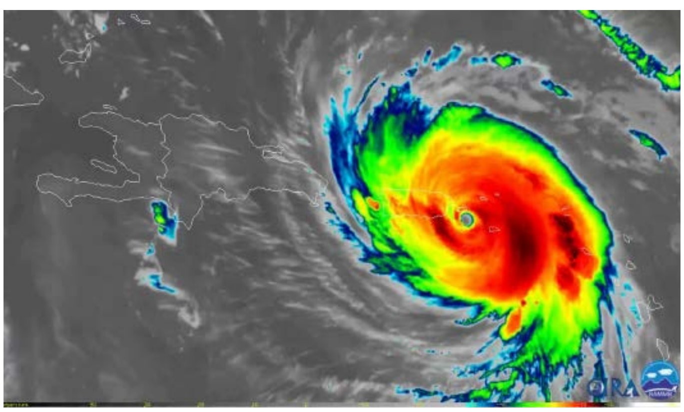

Figure 6. GOES-16 captured this infrared image of Hurricane Maria over Puerto Rico on September 20, 2017. **Image credit:** Colorado Institute for Research in the Atmosphere, Colorado State University

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*.

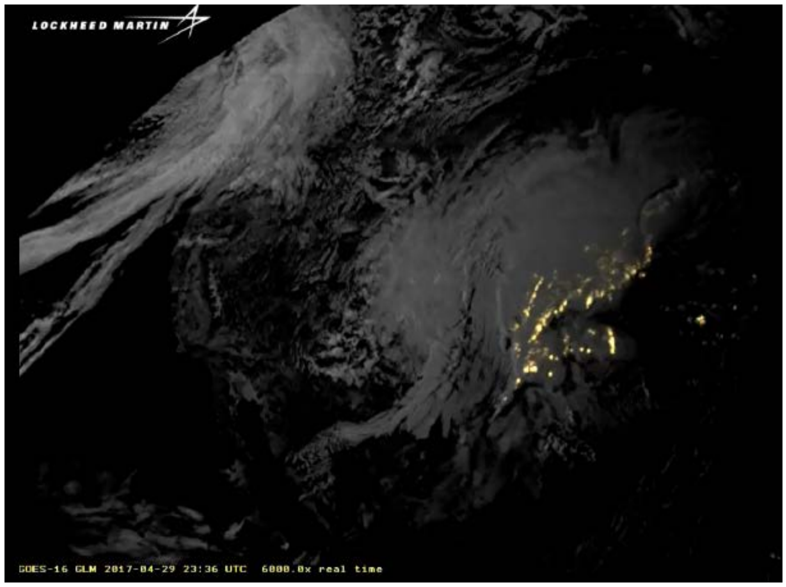

Figure 7. This image, created using data from GOES-16's GLM, shows lightning associated with a severe weather event over the Mississippi Valley and U.S. Southern Plains. The full visualization (URL provided in the main text) begins at approximately noon on Friday, April 28, 2017, and ends at midnight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

"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*]

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.

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.

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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.

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.

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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*.

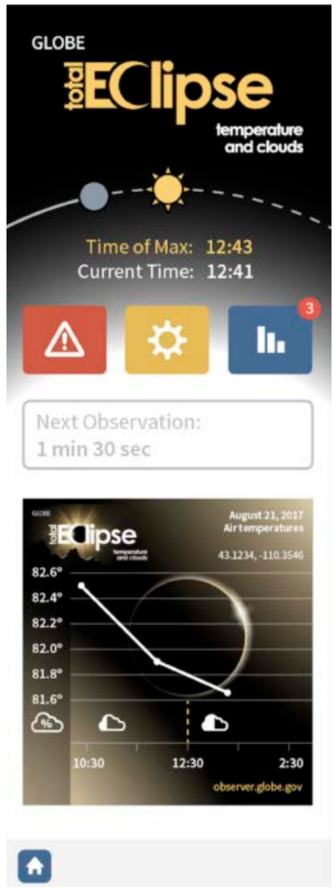

Figure 2. The GLOBE Observer eclipse protocol provided a real-time graph of temperature change at the user's location. **Image credit:** GLOBE

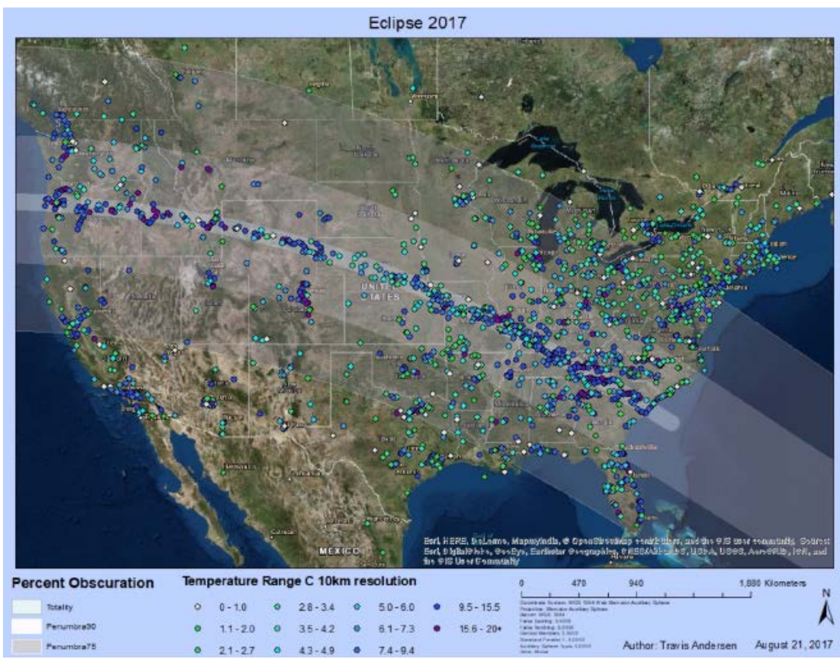

Figure 3. This map shows the change in temperature over a 10-km (~6-mi) grid. All citizen science observations in each 10-km region were averaged to yield a regional temperature change. **Image credit:** Travis Anderson, GLOBE

*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.

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.

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.

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,

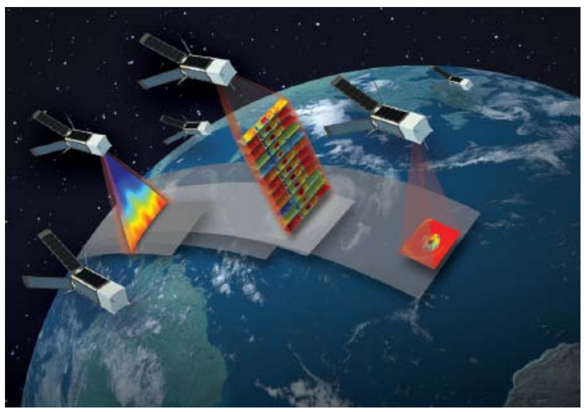

Figure 1. Artist's rendition of the TROPICS mission concept showing the constellation of SmallSats and representations of several aspects of their observing capabilities. Each satellite will measure all three of the data samples shown here. Swath width for TROPICS will be 2025 km (~1258 mi). The nadir 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