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Editor's Corner

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NASA hopes to have two additional Earth science instruments installed on the ISS by the end of 2016. The SpaceX-10, scheduled to launch to the ISS from Cape Canaveral Air Force Base on November 2016, will carry both the Lighting Imaging Sensor (LIS) and Stratospheric Aerosol and Gas Experiment III (SAGE III) instruments to the station.

LIS on ISS builds upon the solid foundation of space-based observations begun with LIS on TRMM and its predecessor, the Optical Transient Detector (OTD[1]), as it continues to measure the amount, rate, and optical characteristics of lightning across Earth. This mission will not only extend LIS time-series observations from TRMM (which will allow scientists to better interpret the inter-relationships between lightning and climate variation), but it will also expand the latitudinal coverage poleward from ±35° to ±54° to encompass the climatically important midlatitudes. Another enhancement of LIS on ISS over its predecessor is the ability to deliver real-time lightning data over data-sparse regions (e.g., the ocean) to operational users. This will improve situational awareness for forecasts, warning decisions, and aviation advisories. In addition, LIS on ISS will enable cross-sensor

[1] OTD was the primary instrument on MicroLab-1, which was a U.S. minisatellite selected to fly under NASA's "Faster, Better, Cheaper" initiative and launched in 1995.

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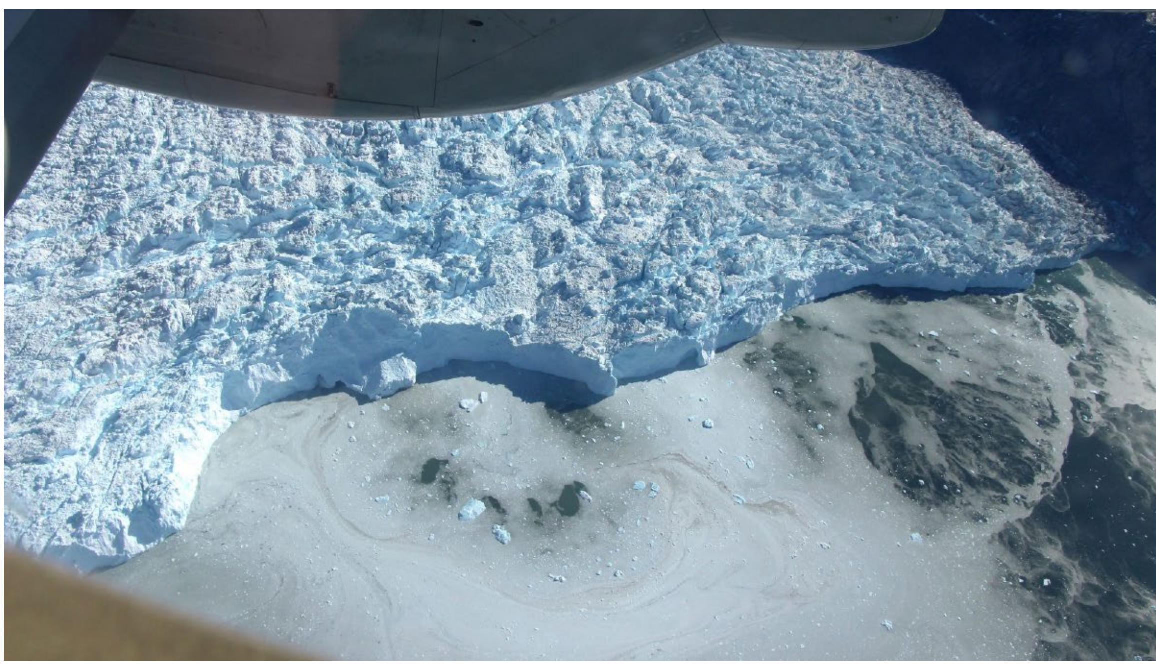

Operation IceBridge, NASA's airborne survey of polar ice, recently completed it's eighth spring Arctic campaign. This image was taken during the Umanaq B mission along Greenland's western coast. This top-down view from a NOAA P-3 aircraft shows the calving front of Sermeq Kujatdleq glacier. The aircraft's #2 lower engine nacelle and left main landing gear fairing is in the foreground at top. Previous measurements from IceBridge have revealed a 460-mi- (740-km-) long canyon hiding under a mile of ice and mapped the extent of a vast liquid water aquifer beneath the snow in southern Greenland. IceBridge's readings of the thickness of sea ice and its snow cover have helped scientists improve forecasts for the summer melt season and have enhanced the understanding of variations in ice thickness distribution from year-to-year. **Image credit:** NASA/John Sonntag

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observations and calibrations, especially for the new Geostationary Lightning Mapper (GLM), which has a design based on LIS heritage and is scheduled for launch later this year onboard NOAA's GOES-R satellite (with subsequent launches on GOES-S, -T, and -U).

To learn more about the plans for LIS on ISS, the history of space-based lightning observations, and plans for the future, please turn to page 4 of this issue. There is also a related news article about research done using data from LIS on TRMM on page 38.

Similar to LIS on ISS for lightning, SAGE III/ISS builds on its own legacy of previous aerosol and gas limb profiling measurements[2]. Having both these instruments on the ISS will allow for comparisons between LIS-inferred lightning nitrogen oxides and the ozone and nitrogen dioxide (NO_2) observations obtained by SAGE III/ISS that reach into the upper troposphere. Combining observations from these two missions will provide new insights to lightning and atmospheric chemistry.

Like LIS, SAGE III/ISS is making progress towards launch. The integrated and environmental-tested Instrument Payload (IP) was delivered to Kennedy Space Center (KSC) in November 2015 and after checkouts it was placed in its storage container along with the Nadir Viewing Platform (NVP) at the Space Station Processing Facility. The SAGE III/ISS team recently returned to KSC and completed final powered testing prior to launch, including undergoing full functional testing on May 6 and the Payload Rack Checkout Unit (PRCU) End-to-End test on May 13. During PRCU testing, the SAGE III/ISS payload was operated from Langley Research Center's Flight Mission Support Center through Marshall Space Flight Center's Operations Integration Center. The team conducted flight payload closeouts the week of May 16 and placed the SAGE III IP and NVP back in storage awaiting launch.

In other news, Operation IceBridge (OIB) concluded its eighth spring Arctic campaign on May 21. OIB is so-named because it is intended to collect data on changing polar land and sea ice and thus "bridge" the "data gap" between ICESat, which ended in 2009, and, ICESat-2, which is scheduled to launch no later than May 2018 and allow for continuity of measurements between the two missions.

[2] To learn more about SAGE III and its heritage, read "SAGE III on ISS: Continuing the Data Record" in the November–December 2015 issue of *The Earth Observer* [**Volume 27**, **Issue 6**, pp. 4-11].

This spring's OIB flights took place on the specially modified NOAA P-3 *Orion* aircraft—see image on front cover. The first leg of the campaign was based out of Thule Air Base in northwest Greenland and out of Fairbanks, AK. A total of six high-priority sea ice flights and two land flights took place from these two locations. The second part was based in Kangerlussuaq, Greenland and focused on gauging surface elevation changes in land ice. Turn to page 36 to learn more details about what took place during the Arctic spring flights of OIB.

On a related note, the Advanced Topographic Laser Altimeter System (ATLAS) is the sole instrument on ICESat-2, and is rapidly progressing toward completion at Goddard Space Flight Center. The instrument will enter thermal-vacuum testing in June 2016, and is scheduled for delivery to Orbital-ATK for observatory integration no later than October 2016. Following observatory integration and testing, the completed ICESat-2 observatory will proceed to Vandenberg Air Force Base. OIB is funded through 2019, to allow for significant overlap in airborne and spaceborne measurements of ice sheet elevation change and sea ice freeboard.

Even as we prepare for new missions, some missions continue to endure the test of time. For example, a series of NASA–USGS Landsat missions have been producing high-resolution images of Earth's land surface for over 40 years. Landsat 7 has now been in orbit for 17 years and continues to operate well, with scientists and engineers coaxing maximum science out of the aging hardware. Landsat 7's *duty cycle*[3] has been extended to 105%, which effectively increases the number of acquisitions during the Northern Hemisphere growing season, as well as in Africa and Central America. Options for extending the Landsat 7 mission, which could allow for continued operation until the launch of Landsat 9 (discussed later), are being explored. The USGS will make a determination on potential options for extending the Landsat 7 mission no later than December 2016.

Meanwhile, Landsat 8 continues to perform well three years after launch. Reprocessing of the Thermal Infrared Sensor (TIRS) data collected since November 2015 has now been completed. There is an ongoing Landsat Global Archive Consolidation (LGAC) effort that seeks to repatriate data from international ground stations. Data from Pakistan, Thailand, and Saudi Arabia have recently been added. Remaining work includes improving ingested data that are not capable of meeting Level-1T[4] specifications, refining processes to retrieve data off old media formats, addressing parts and equipment concerns, and developing necessary Multispectral Scanner (MSS) data format conversion tools. Overall, more than 3.5 million scenes have been recovered so far. For more details on LGAC status and direction, visit *dx.doi.org/10.1016/j.rse.2015.11.032.*

With regard to future land imaging plans, the Landsat 9 Project is underway, and is working toward a launch in late 2020. Beyond that, the Sustainable Land Imaging (SLI) Program lays groundwork for establishing a long-term (i.e., ~20-year) vision for Landsat 10 and beyond. Activities within USGS and NASA are focusing on assessing long-term user needs and available technologies, respectively. To learn more about the current status of and plans for future Landsat missions, as well as related research and applications, see the Landsat Science Team meeting summary on page 19 of this issue.

I am also happy to announce that as of April 1, 2016, all data products from the ASTER instrument onboard Terra are now available at no charge. (Prior to this, users could obtain select data products over the U.S. and its territories at no charge, but paid a nominal fee to Japan's Ministry of Economy, Trade, and Industry (METI) to order international data products.) With this change in policy, ASTER data users now have open access to nearly three million individual scenes covering 99% of Earth's landmass between ±83° latitude. Data from ASTER are used to create detailed maps of land surface temperature, reflectance, and elevation, and provide critical information for surface mapping and the monitoring of dynamic conditions and changes over time. Applications of ASTER data include tracking glacial advances and retreats, monitoring potentially active volcanoes, identifying crop stress, determining cloud morphology and physical properties, evaluating wetlands, assessing coral reef degradation, mapping surface soil temperatures, and measuring surface heat balance. To learn more about this change in policy, see the announcement on page 34 of this issue.

Finally, as it has done for the last several years, NASA teamed with Earth Day Network to commemorate Earth Day. This year, events took place at Union Station in Washington, DC, April 21-22. To view pictures from the event and learn about the different kinds of hands-on activities that were offered, as well as other interesting outreach endeavors that took place, turn to page 15 of this issue. ■

[3] In this context, the term "duty cycle" refers to increasing the number of Landsat 7 acquisitions over and above its specified acquisition rate.

[4] Level 1T is the standard Landsat data product distributed by USGS EROS. The products provide *orthorectified* (i.e., radiometrically and terrain corrected) image products.

Note: List of undefined acronyms from the *Editor's Corner* and the *Table of Contents* can be found on **page 43**.

LIS on ISS: Expanded Global Coverage and Enhanced Applications

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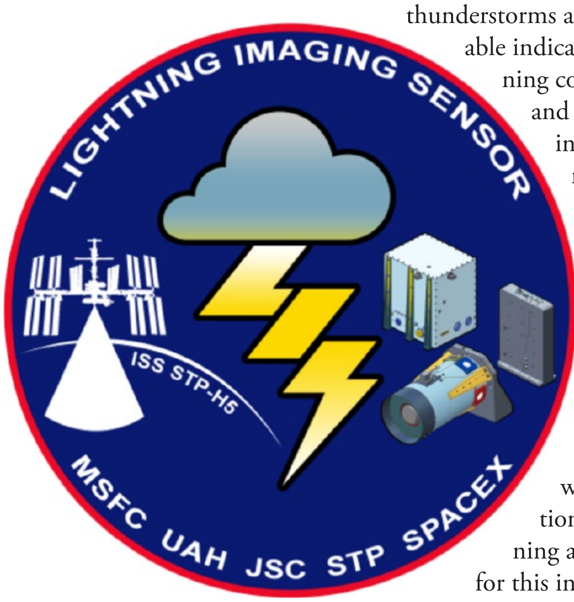
Introduction

Lightning is an impressive and direct response to intense atmospheric convection. Because lightning is intimately tied to thunderstorm microphysics and dynamics, it can be used to remotely probe the developmental state, severity, and evolution of thunderstorms and thunderstorm complexes, and can also serve as a valuable indicator for monitoring long-term climate change. Overall, lightning conveys useful information about many atmospheric processes and provides scientific insight across a broad range of disciplines, including weather, climate, atmospheric chemistry, and lightning physics. To support these useful measurements, NASA's Marshall Space Flight Center (MSFC) and other science, academic, and commercial partners pioneered the observing technology that has made global-scale lightning detection from space a reality.



NASA's first space-based lightning sensor, called the Optical Transient Detector (OTD), was launched aboard the MicroLab-1 satellite[1] in 1995 from Vandenberg Air Force Base. The primary mission of the OTD instrument was to improve the understanding of thunderstorm distributions, cloud processes, and storm variability by detecting lightning activity over large areas of the Earth's surface. The concept for this instrument was developed at MSFC in the 1980s, and was selected for development as part of NASA's Earth Observing System (EOS). The concept implementation, the Lightning Imaging Sensor (LIS), was selected as an EOS instrument[2] to fly on both a polar platform and the International Space Station (ISS), which was then known as Space Station *Freedom*. All the EOS instruments for ISS were descoped within a year or so because NASA's focus shifted to just getting ISS built. Later, as the Tropical Rainfall Measuring Mission (TRMM) instrument complement was being finalized, LIS was moved to TRMM because of the strong synergies of LIS with the core TRMM science instruments. TRMM, with LIS onboard, was launched in November of 1997. When LIS on TRMM was developed and built, an identical spare instrument was also built. Now, that spare is finally being put to use. Planned for launch in November 2016, the spare LIS instrument will be mounted on the ISS for a two-year or longer mission.

Overall, lightning conveys useful information about many atmospheric processes and provides scientific insight across a broad range of disciplines, including weather, climate, atmospheric chemistry, and lightning physics.

This article provides a detailed discussion of the LIS on the ISS mission, including a timeline of space-based lightning and related missions, mission overview, instrument description, launch and installation details, and science operation and data management techniques.

Timeline of LIS on ISS and Related Space Missions

Prior to 1995, space-based lightning observations had been severely limited by one or more problems, including low or unknown detection efficiency, poor spatial and temporal

[1] MicroLab-1 was a U.S. minisatellite that was launched by a Pegasus rocket carried aloft by an L-1011 aircraft flying out of Vandenberg Air Force Base. OTD, a space-qualified LIS engineering model, was selected to fly under NASA's "Faster, Better, Cheaper" initiative, and was the primary instrument onboard MicroLab-1; the other instrument was a radio receiver to monitor the transmission from Global Positioning System (GPS) spacecraft.

[2] Early plans for the EOS platforms are summarized in "The Earth Observer: 20 Years Chronicling the History of the EOS Program" in the March–April 2008 issue of *The Earth Observer* [**Volume 20**, **Issue 2**, pp. 4-8].

resolution, a limited number or brief periods of observations, and an inability to measure lightning during the daytime, leading to incomplete sampling over the diurnal cycle. The launch of OTD ushered in a new era of space-based lightning detection, being specifically designed to address the deficiencies of available ground-based, *in situ*, and space-based lightning measurements. In particular, it provided—for the first time—highly detailed and accurate statistics of the geographical distribution of lightning frequency, worldwide.

The launch of OTD ushered in a new era of space-based lightning detection, being specifically designed to address the deficiencies of available ground-based, in situ, and space-based lightning measurements.

The OTD was positioned in a near-circular orbit at an altitude of 740 km (~460 mi), at a 70° inclination. This orbit provided observations of lightning activity over most regions of the world where lightning is generated (coverage between 75° N and S latitude). During OTD's five-year mission, the instrument optically detected lightning—both intracloud and cloud-to-ground discharges—that occurred within its 1300 x 1300 km (~808 x 808 mi) footprint during both day and night. The instrument also had storm-scale [~10 km (~6 mi)] spatial resolution, two-millisecond time resolution, and high, uniform detection efficiency (~50%).

With the launch of TRMM, LIS joined OTD at an altitude of 350 km (~217 mi) and 35° inclination orbit[3]. LIS on TRMM represented a significant advance upon OTD with its sensitivity improved by a factor of three. The increased sensitivity of LIS resulted in a detection efficiency approaching 90%, while its lower orbit altitude improved its spatial resolution to 4 km (~2.5 mi), but at the cost of a decreased surface footprint of 600 x 600 km (~373 x 373 mi)—see **Figure 1**. Although LIS

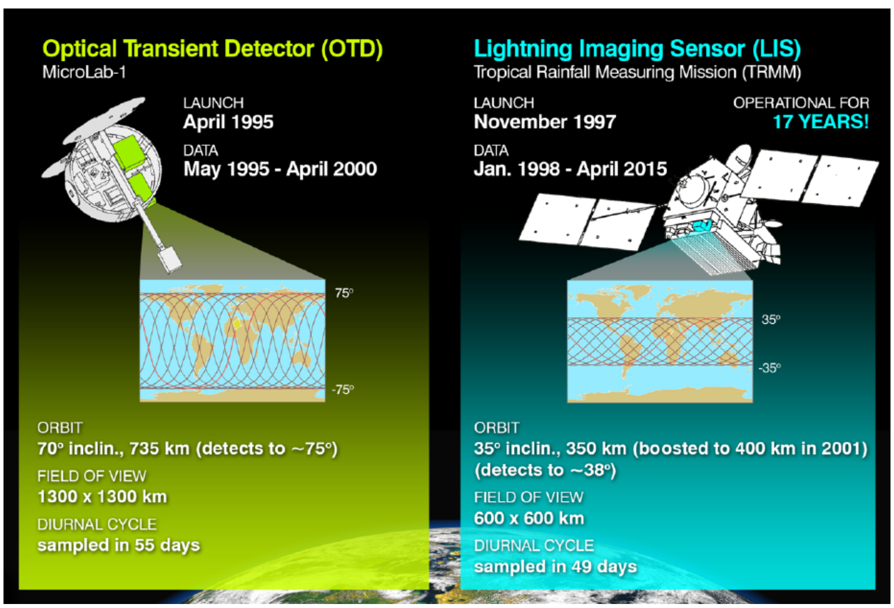


Figure 1. Since 1995, OTD and LIS on TRMM have provided 20 years of continuous combined lightning observations to create a robust global lightning climatology throughout the diurnal cycle. **Image credit:** NASA and the University of Alabama in Huntsville (UAH)

provided smaller global coverage than OTD, it still is thought to have detected 90% of of the world's lightning on an annual basis. An important science benefit of flying on TRMM was the acquisition of LIS lightning measurements simultaneous with TRMM visible, infrared, microwave, and radar observations, which provided the capability to directly test a number of hypotheses on the interrelationships between updrafts, ice formation, and lightning over a large number of global tropical cloud regimes from a space-borne platform. LIS on TRMM operated for an impressive 17 years.

[3] TRMM was boosted to an altitude of 402 km (250 mi) in August 2001; its mission ended in April 2015.

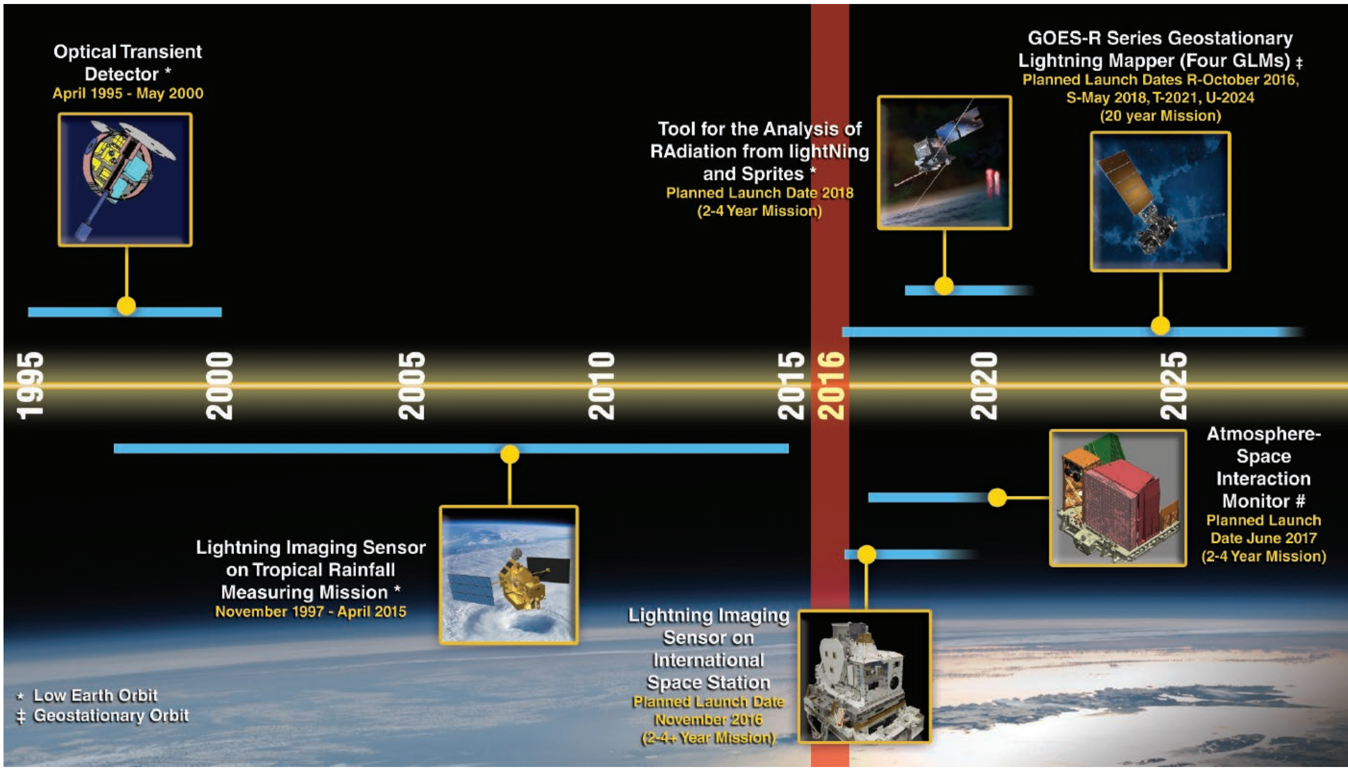


Figure 2. A timeline showing LIS on ISS, along with several closely-related space missions. **Image credit:** NASA

The heritage OTD and LIS instruments were essential steps along the path toward getting a LIS onboard the ISS—see **Figure 2** and the section to follow.

Mission Overview

As mentioned earlier, the space-qualified LIS—built as the flight-spare for TRMM—is now scheduled to be delivered to the ISS as a hosted payload on the Space Test Program-Houston 5 (STP-H5) mission. This mission is integrated and flown under the management and direction of the Department of Defense Space Test Program. Discussion of the launch, ISS installation, and mission activation appears on page 10.

LIS on ISS will build upon the solid foundation of space-based observations begun with LIS on TRMM and its OTD predecessor, as it continues to measure the amount, rate, and optical characteristics of lightning across Earth.

LIS on ISS will build upon the solid foundation of space-based observations begun with LIS on TRMM and its OTD predecessor, as it continues to measure the amount, rate, and optical characteristics of lightning across Earth—see *LIS on ISS Science Goals* below. Of particular note is that LIS daytime lightning detection is both unique and scientifically important, since more than 60% of lightning occurs during daylight hours.

LIS on ISS Science Goals

- Examine the uses of lightning for improving severe weather warning.
- Extend the global lightning climatology record.
- Estimate lightning nitrogen oxides (LNO_x) to improve chemistry/climate and air-quality modeling.
- Determine the interrelationship between lightning, clouds, and precipitation.
- Examine the detailed physics of the lightning discharge.

Moreover, there are many unique benefits gained by flying LIS on the ISS that especially enhance the science value of this mission. The orbit of ISS will not only extend LIS time-series observations from TRMM that will allow scientists to better interpret the interrelationships between lightning and climate variation, but it will expand the latitudinal coverage poleward to 54° to encompass the climatically important midlatitudes—see **Figure 3**.

LIS on TRMM missed up to an estimated 30% of the lightning in the Northern Hemisphere's warm season months[4], but LIS on ISS will detect nearly all that "missed" lightning. The expanded areal coverage will allow observations of midlatitude storms over the Continental United States (CONUS), middle and southern Europe, and storm tracks over the midlatitude oceans, collectively leading to enhancements in regional and global weather, climate, and chemistry models, studies, and assessments.

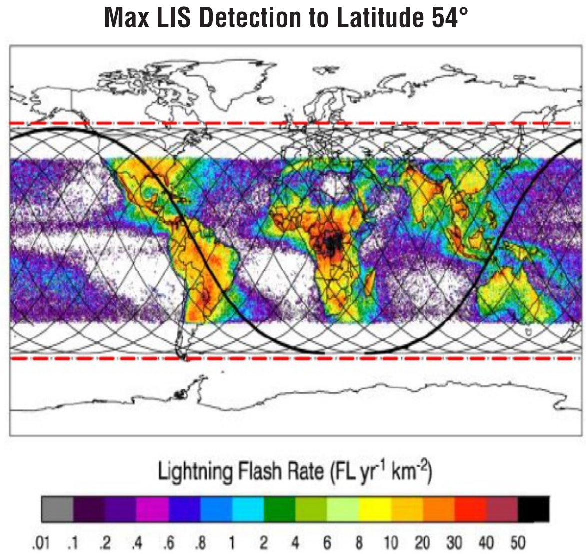


Figure 3. The global-scale coverage of LIS on ISS (between the dashed lines) is shown superimposed upon the annual lightning climatology from TRMM—which observed lightning poleward to 38°. While the areal coverage from ISS only encompasses 81% of Earth's surface, it enables LIS to detect 98% of the lightning on an annual basis (compared to 62% of the surface area and 90% of the annual lightning for LIS on TRMM). **Image credit:** NASA

Providing real-time lightning data over data-sparse regions (e.g., over the ocean) to operational users will improve situational awareness for forecasts, warning decisions, and aviation advisories. In addition, the mission will enable cross-sensor observations and calibrations, especially for the new Geostationary Operational Environmental Satellite-R Series (GOES-R) Geostationary Lightning Mapper [GLM], which has a design based on LIS heritage and is scheduled for launch in October 2016. (Subsequent launches carrying copies of GLM are planned in 2018, 2021, and 2024 onboard GOES-S, -T, and -U, respectively.) Furthermore, there are plans to seek an extension of LIS on ISS beyond the planned two-year timeframe in order to extend cross-sensor observations and calibrations to the European Meteosat Third Generation Lightning Imager (MTG-LI), currently scheduled for launch in 2019. The intercomparisons between LIS and GLM and between LIS and MTG-LI would effectively allow for transitive cross-hemispheric comparisons between the two geostationary missions[5]. Coincidence datasets collected between LIS on ISS and members of the recently launched Global Precipitation Measurement (GPM) mission satellite constellation[6] will enable fusion and study of active and passive microwave measurements of clouds and precipitation and associated responses in lightning activity, similar to TRMM but now expanded over a much larger region of the globe and much larger sample of cloud and precipitation regimes. Also, the ISS platform will uniquely enable LIS to provide simultaneous and complementary observations with other ISS payloads, such as the European Space Agency's Atmosphere-Space Interaction Monitor (ASIM), which is exploring the connection between lightning and terrestrial gamma-ray flashes (TGFs), and NASA's Stratospheric Aerosol and Gas Experiment III (SAGE III)/ISS mission[7].

Providing real-time lightning data over data-sparse regions (e.g., over the ocean) to operational users will improve situational awareness for forecasts, warning decisions, and aviation advisories.

Instrument Description

The legacy LIS instrument selected for this mission has been carefully maintained in environmentally controlled storage since 1998, effectively providing an available off-the-shelf instrument for this ISS opportunity. Although this instrument is

[4] Thunderstorm frequency over the significant landmasses in the Northern Hemisphere outside the TRMM coverage region increases dramatically between the spring and fall equinoxes, with the northern displacement and associated heating of the sun. In the Southern Hemisphere, there is little landmass outside of the TRMM coverage region, so no comparable loss in lightning detection occurs during the Southern Hemisphere's warm-season months, since lightning occurs predominately over land.

[5] Because LIS has near-global coverage, it essentially acts as a "transfer standard" allowing comparisons between GLM and MTG-L1, which cover only the western and eastern hemispheres, respectively.

[6] Global Precipitation Measurement (GPM) is an international satellite mission to provide next-generation observations of rain and snow worldwide every three hours.

[7] For more information, see "SAGE III on ISS: Continuing the Data Record" in the November–December 2015 issue of *The Earth Observer* [**Volume 27**, **Issue 6**, pp. 4-11].

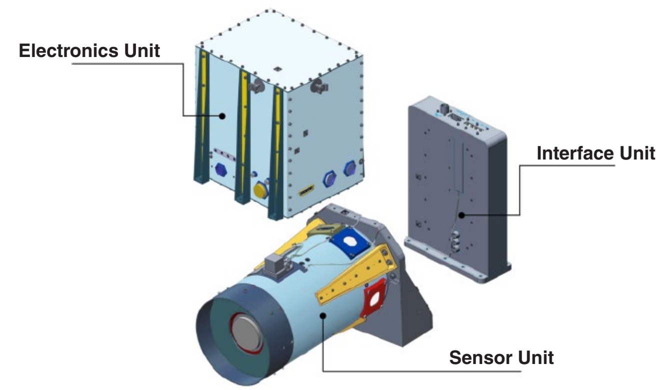


Figure 4. The heritage LIS hardware consists of the Sensor and Electronic Units. In order to operate on the ISS without modification to the instrument, a new Interface Unit was developed that makes the ISS appear like the TRMM spacecraft to the LIS instrument. **Image credit:** NASA and UAH

nearly 20 years old, its controlled storage and solid TRMM operating heritage—i.e., as noted earlier, LIS on TRMM having performed well for 17 years in space—give a high degree of confidence that this flight spare will perform without problems once launched. A recalibration of the flight-spare LIS performed in preparation for this ISS mission showed its performance and calibration has remained unchanged. It is also worth noting that by monitoring the reflected sunlight from deep convective clouds, LIS on TRMM showed no degradation in its sensitivity during its many years in orbit.

The LIS instrument is a small, solid-state, optical imager optimized to detect and pinpoint lightning from thunderstorms within its field of view, mark the time of occurrence, and measure the radiant energy.

The LIS instrument is a small, solid-state, optical imager optimized to detect and pinpoint lightning from thunderstorms within its field of view, mark the time of occurrence, and measure the radiant energy. The instrument primarily operates as a transient event detector, although it also provides periodic background images that help with long-term navigation and calibration monitoring. The sensor design was driven by the requirement to detect weak lightning signals during the day when the sunlight reflecting from the tops of clouds is much brighter than the illumination produced by lightning. This requirement was met by optimally sampling the lightning signal relative to the bright solar background in the spatial, temporal, and spectral domains—see *How LIS Lighting Detection Works* on the next page.

LIS is divided into a Sensor Unit and an Electronics Unit. The Sensor Unit contains a wide-field-of-view lens, combined with a narrow-band interference filter centered on a strong emission line in the lightning spectrum (i.e., the oxygen multiplet at 777.4 nm), which focuses the image on a high-speed, 128 x 128-pixel charge-coupled device (CCD) focal plane. The signal is read out from the focal plane at 500 images per second into the real-time event processor located within the Electronics Unit for event detection and data compression. As risk mitigation for the ISS mission, a new Interface Unit was designed and built to make the ISS platform appear like the TRMM spacecraft to the LIS instrument so that no modifications would be necessary with the legacy hardware. **Figure 4** shows the LIS hardware, while **Table 1** summarizes the overall instrument parameters and performance criteria.

Table 1. This table summarizes the overall instrument parameters and performance criteria, where nm means nanometer and μJ m^{-2} sr^{-1} means micro Joules per meter squared per steradian.

Field-of-View (FOV)	80° × 80°	**Measurement Accuracy**	
Pixel IFOV (nadir)	4 km	*location*	1 pixel
Interference Filter		*intensity*	10 %
wavelength	777.4 nm	*time*	tag at frame rate
bandwidth	1 nm	**Dimensions**	
Detection Threshold	4.7 μJ/m^2sr	*sensor unit*	7.8 x 14.6 in (20 x 37 cm)
Signal to Noise Ratio	6	*electronics unit*	12.2 x 8.7 x 10.6 in (31 x 22 x 27 cm)
CCD Array Size	128 x 128 pixels	*interface unit*	9.8 x 2.4 x 13.8 in (25 x 6 x 35 cm)
Dynamic Range	> 100	**Weight**	55 lbs (25 kg)
Detection Efficiency	~ 90 %	**Power**	35 W
False Event Rate	< 5 %	**Telemetry Data Rate**	8 kilobytes/second

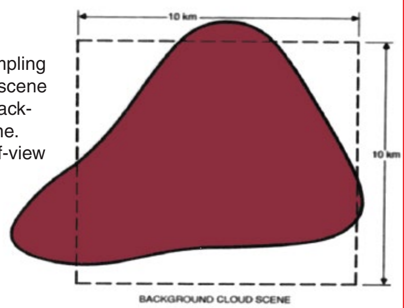
How LIS Lightning Detection Works

When viewed from space, lightning appears as a diffuse pool of light on top of the cloud. During the day, sunlight reflected from the cloud top totally masks the lightning signal. What makes LIS on ISS unique is its ability to detect lightning during daytime hours, when 60% of lightning discharges occur. LIS on ISS does this by using *optimum sampling techniques*. These techniques are applied to extract the weak, transient lightning signal from the bright background, using four filtering approaches—see the four figures below. This filtering results in a 10^5 reduction in data rate requirements, while producing high lightning-detection efficiency.

Image of lightning from space taken from the ISS over Myanmar on April 20, 2013. **Photo credit:** NASA

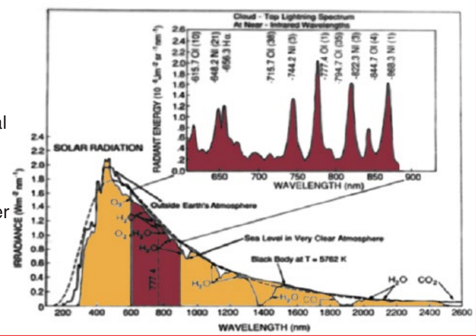
Spatial

Optimal sampling of lightning scene relative to background scene. Pixel field-of-view 4-8 km.



Spectral

Optimal sampling of lightning signal relative to background signal. LIS uses 1 nm filter at 777.4 nm.

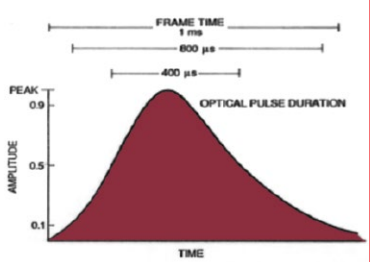


The individual pixels are matched to the smallest area that is typically illuminated by a lightning discharge in a thunderstorm, thereby helping to maximize the lightning signal relative to the reflected sunlight. For example, if the pixel footprint shown [*above left*] were made larger, more sunlight would be added to the pixel with relatively little additional lightning signal, thereby decreasing the signal-to-noise ratio.

A narrowband interference filter in the near infrared, centered on a strong emission feature in the lightning spectrum, further enhances the lightning signal relative to the reflected sunlight.

Temporal

Optimal sampling of lightning pulse relative to background signal. LIS uses 2 ms frame rate.



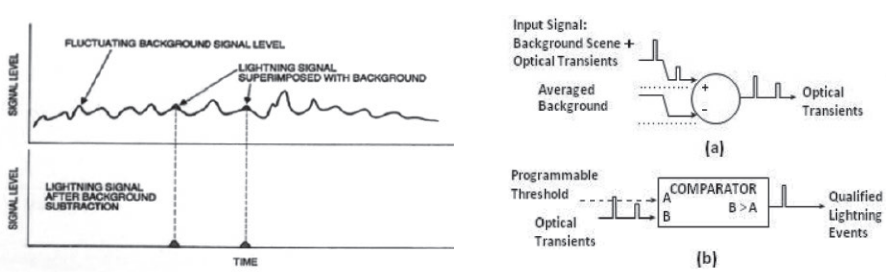
A two-millisecond focal plane frame integration time that approximately matches the lightning optical pulse width provides a third approach for enhancing the lightning signal over the solar background [*left*].

Even with the spatial, spectral, and temporal filters described above, the solar background can still exceed the lightning signal by 100-to-1 at the focal plane. The final step, therefore, is to apply a frame-by-frame background subtraction [*below*]. to remove the slowly varying solar background signal, so that the residual represents a detectable lightning transient.

Background Subtraction

Optimal subtraction of background signal levels at each pixel.

Transient events selected for processing.



Launch, Installation, and Mission Activation

The STP-H5 payload containing LIS is scheduled to launch from NASA's Kennedy Space Center to the ISS in November 2016, aboard the SpaceX Cargo Resupply Services-10 (SpaceX-10) mission. For this launch STP-H5 will be installed in the unpressurized "trunk" of the Dragon spacecraft. During launch and throughout the two-day trip to reach the ISS, the Dragon spacecraft provides power to the STP-H5 survival heaters, one of which is mounted on the LIS Sensor Unit.

The STP-H5 payload containing LIS is scheduled to launch from NASA's Kennedy Space Center to the ISS in November 2016, aboard the SpaceX Cargo Resupply Services-10 (SpaceX-10) mission.

After the Dragon is berthed to the ISS Node 2 Nadir port, the STP-H5 payload will be removed from the trunk using the Canadarm2 and the Special Purpose Dextrous Manipulator (SPDM, or "Dextre") attached to Canadarm2. The STP-H5 payload will be installed at ExPRESS Logistics Carrier-1 (ELC-1) in a nadir-viewing location—see **Figure 5**. The installation of STP-H5 at the ELC-1 position requires that it be swapped with the Optical Payload for Lasercomm Science (OPALS), currently installed at that location. OPALS will be installed back into the Dragon trunk for disposal when the trunk is jettisoned as the Dragon capsule prepares for its return to Earth.

The transfer of STP-H5 is unique in that the STP-H5 is grasped at two locations. The primary grasp is with the Flight Releasable Attachment Mechanism (FRAM) H-Handle, used to mechanically unlock or lock the FRAM into place in the Dragon trunk and the ELC site. The second grasp location is on the face of the payload. This grasp provides a secondary mechanical hold on the payload, as well as power to the survival heaters to maintain safe temperature levels for the payload during its transfer from the Dragon trunk to the ELC. Following the installation of STP-H5 on the ISS, the LIS Operations Team will work with the STP-H5 and ISS Operations Teams to power-on the LIS and begin instrument checkout and commissioning.

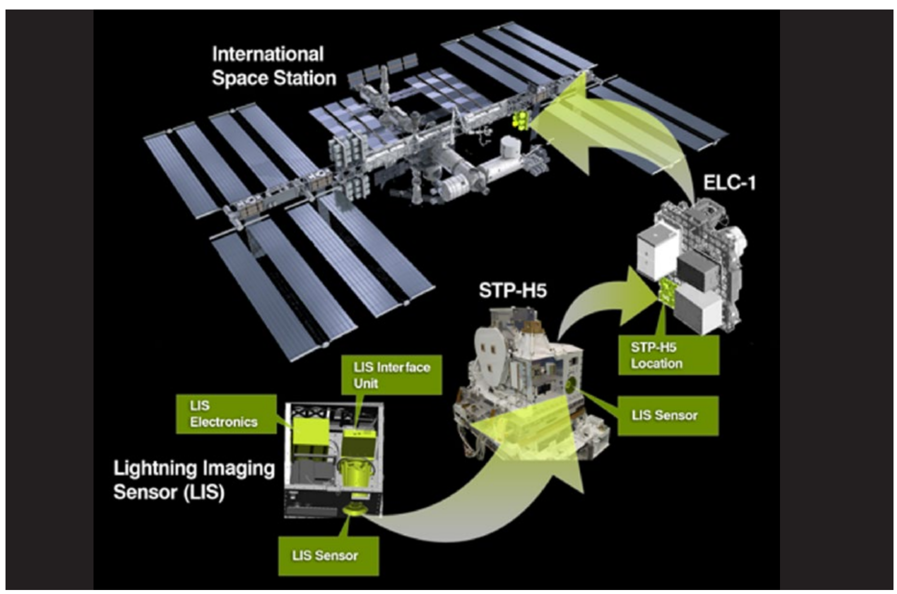


Figure 5. The graphic shows where the LIS hardware is installed within the STP-H5 payload, and where the STP-H5 is installed on ELC-1 in a nadir-viewing position. **Image credit:** NASA and UAH

Science Operations and Data Management

Orbital science operations will be managed from the newly established LIS Payload Operations Control Center (LIS POCC), located at the National Space Science and Technology Center (NSSTC) in Huntsville, AL. Activities from the LIS POCC will be conducted during the work week at regular business hours, and will include monitoring the operation of the LIS and its science and housekeeping data, and commanding the instrument as necessary. More extensive 24/7 monitoring of the LIS will be provided by the Payload Operations Integration Center (POIC) at MSFC.

The LIS data handling involves a close partnership between the LIS Science Team and the Global Hydrology Resource Center (GHRC), one of NASA's Distributed Active Archive Centers (DAACs) that extends to the earlier OTD and LIS on

TRMM missions—see **Figure 6.** The well-established and robust processing, archival, and distribution infrastructure used for TRMM was easily adapted to the ISS mission. This assures that lightning data observations from LIS on ISS can be quickly delivered to science and application users soon after routine operations are established and underway. Real-time data, available for the first time with this mission, will be provided to interested users in partnership with NASA's Short Term Prediction Research and Transition (SPoRT) Center, also located at the NSSTC. A full suite of space-based lightning observations is available from the GHRC DAAC (*ghrc.nsstc.nasa.gov*). The LIS data products consist of geolocated and time-tagged lightning events, *background images* ("snapshots" of the LIS CCD acquired about every 30 seconds, depending on the flash rate), and orbit statistics and metadata. Visit the GHRC's lightning data portal (*lightning.nsstc.nasa.gov/data/index.html*) to access these and other lightning datasets, related tools, and documentation[8].

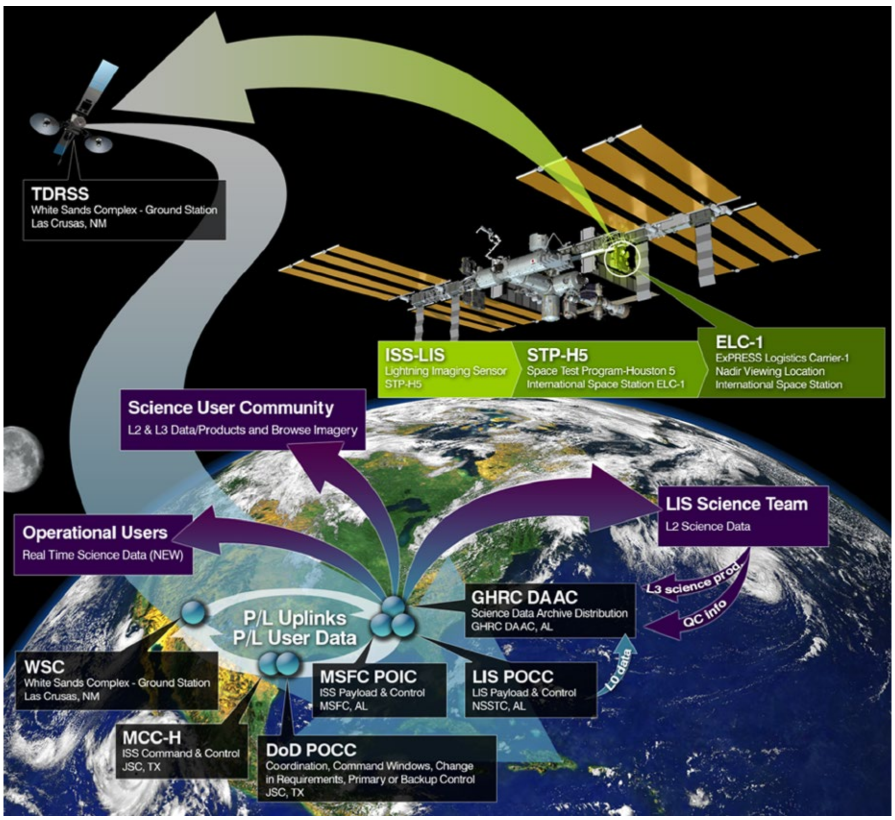


Figure 6. This graphic shows the data flow from the LIS instrument to the LIS POCC and GHRC DAAC, where the data will be processed, archived, and distributed to the science community and operational users. **Image credit:** NASA and UAH

Research Areas and Applications

Data from the LIS on ISS mission will be applied to several scientific studies including examining the relationship between lightning and severe weather; extending the global lightning climatology; estimating lightning nitrogen oxides (LNO_x) for lightning chemistry applications; determining the interrelationships between lightning, cloud properties, and precipitation; and examining the detailed physics of lightning. All of these elements of investigation are intertwined to varying extents. For example, a better understanding of the interrelationships between lightning, precipitation, and severe weather, coupled with an extended lightning climatology record, provides a better understanding of extreme storm statistics and how hurricane intensity and lightning flash rate are related. Coincident observations of atmospheric aerosol content with lightning and precipitation structure will also provide information for examining the complex interplay between the background aerosol environment,

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[8] LIS science products and the algorithms used to generate them are described in the Algorithm Theoretical Basis Document (*lightning.nsstc.nasa.gov/bookshelf/pubs/atbd-lis-2000.pdf*). Derived products include gridded climatologies from the OTD and LIS on TRMM data record, at 0.5° and 2.5° resolutions (*dx.doi.org/10.1016/j.atmosres.2012.06.028*), as well as a new set of very-high-resolution 0.1° climatologies (*dx.doi.org/10.1175/BAMS-D-14-00193.1*).

cloud physics, and lightning. Similarly, an extended lightning climatology record, coupled with improved LNO_x estimation (from an improved understanding of lightning channel physics), provide improved understanding of lightning/climate relationships. Many other examples can be obtained by combining the various science goals in different ways.

Severe Weather

Data from OTD, LIS on TRMM, and ground-based regional lightning detection systems have been employed to better understand the relationship between variations in the total (i.e., intracloud plus cloud-to-ground) flash rate in a thunderstorm, and the thunderstorm's tendency to produce severe weather (e.g., high winds, damaging hail, tornadoes). Sudden increases in the total lightning flash rate, referred to as *lightning jumps*, are considered to be precursors to a severe weather outbreak, and these jumps provide improved severe-weather warning lead-time (i.e., between 10 and 20 minutes before the event). Consequently, it has been possible to build a baseline lightning jump severe weather warning algorithm for the GOES-R GLM. However, the interrelationships between lightning jumps and severe weather outbreaks are by no means clean cut, and additional studies are needed to take full advantage of the information content of lightning phenomenology. For example, not all flashes are equal in terms of energetics, and hence the lightning jump algorithm might be further improved by taking into consideration the energy of each lightning flash, as opposed to just counting flashes in a particular time interval to obtain flash rate. Hence, there is a desire to use ancillary LIS on ISS data (e.g., flash brightness, areal extent, duration) that help define overall flash energy, in order to further examine and optimize the baseline lightning jump algorithm.

Data from OTD, LIS on TRMM, and ground-based regional lightning detection systems have been employed to better understand the relationship between variations in the total (i.e., intracloud plus cloud-to-ground) flash rate in a thunderstorm, and the thunderstorm's tendency to produce severe weather.

In addition, LIS on ISS data will be used for air-traffic advisories, similar to how LIS data was used during the TRMM mission. The LIS data will be provided to national forecast offices and the National Oceanic and Atmospheric Administration (NOAA) Aviation Weather Center (AWC) to identify convective weather hazards, particularly over the ocean where ground-radar coverage is limited. Forecasters will be able to overlay the LIS data with conventional visible and infrared satellite imagery to understand which convective cells have an increased chance of turbulence.

Lightning Climatology

The OTD and TRMM LIS data have been applied to obtain robust maps of the worldwide geographical distribution of lightning frequency; it is very important that LIS on ISS continue this essential climatological data record. For example, the global diurnal variability of lightning flash rate is intimately connected to the climatological variation of many atmospheric processes including global temperature; storm frequency, intensity, and distribution; and the global electric circuit. An extended lightning climatology record also provides improved statistical information that allows for creating several useful products for the research community, such as higher spatial resolution lightning climatologies and new thunderstorm-scale databases that combine lightning information with other products (e.g., hydrometeor content, radar reflectivity information, and brightness temperature).

Chemistry

Since LIS observes the diffuse cloud-top optical emissions from lightning discharges, it will provide important information about the energetics of each flash, which in turn can be related to the thermochemical yield of LNO_x. The LNO_x are important trace gases that impact the concentration of tropospheric ozone (O_3; a greenhouse gas), and hydroxyl (OH) radicals that are highly reactive and affect the concentration of all other greenhouse gases. Therefore, LIS on ISS data will play a significant role in improving both coupled global climate–chemistry models and regional air quality models. First-time comparisons between LIS-inferred LNO_x, and the O_3 and nitrogen dioxide (NO_2) observations that will be provided by SAGE III/ISS, which will launch concurrently with LIS, will provide new insights to lightning and atmospheric chemistry. SAGE III/ISS O_3 profile measurements penetrate deeper into the atmosphere reaching down into the troposphere and can be compared with LIS lightning chemistry results. Since climate is most sensitive to O_3 in the upper troposphere and since LNO_x is the most important source of NO_x in the upper troposphere at tropical and subtropical latitudes, lightning is a particularly good parameter to monitor for climate assessments.

Precipitation

Lightning is primarily linked to ice-phase precipitation processes produced by strong updrafts in individual thunderstorm cells that have a mixed-phase distribution of *hydrometeors* (i.e., presence of supercooled water droplets, ice crystals, and graupel particles, important for cloud electrification). Hence, it is no surprise that the characteristics of lightning are coupled to the characteristics of cold-cloud precipitation, and *vice versa*. Cold precipitating clouds are usually associated with intense storms, which are predominantly found over continental landmasses during the summer (in both hemispheres), when they intrude deep into the middle and high latitudes of Earth's continents. Precipitating clouds of this type also occur over isolated ocean regions during winter, where the mid- and high-latitude storm tracks are most active.

Similar to LIS on TRMM, LIS on ISS will fly within the view of the GPM satellite constellation, enabling frequent coincident sampling between GPM precipitation remote sensing platforms and LIS on ISS across the Earth's tropical and higher latitudes. This will enable measurements from GPM—which is rapidly assembling one of the most complete collections of active and passive precipitation measurements ever assembled—to be combined with total lightning information over a large fraction of the globe.

Similar to LIS on TRMM, LIS on ISS will fly within the view of the Global Precipitation Measurement (GPM) satellite constellation, enabling frequent coincident sampling between GPM precipitation remote sensing platforms and LIS on ISS across the Earth's tropical and higher latitudes.

Evolving from the TRMM era, it will also be important to use data from LIS on ISS to continue building and extending cloud and precipitation feature (CPF) databases that focus on thunderstorm-scale events, pairing individual convective cells with associated microphysical properties, brightness temperatures, and lightning-flash characteristics. From this perspective, the lightning information may well be useful for improving the algorithms developed to characterize and estimate precipitation from GPM. At a minimum, the CPF databases can be used to help evaluate and possibly improve passive microwave precipitation retrievals. Multiple CPF databases have now been used to analyze the regional, seasonal, and diurnal variations of precipitation and to document deep convection in the tropics. Because of the higher latitudinal coverage, the ISS data will also allow for new investigations on the effects of topography, more extreme changes of season, forcing by large mid-latitude cyclones, and even investigating lightning response to the transition of warm-core hurricanes to cold-core mid-latitude cyclones on both precipitation and lightning.

Discharge Physics

LIS on ISS will continue to offer detailed insight into the physics of lightning discharges. For example, each LIS-detected lightning flash is composed of one or more diffuse cloud-top emissions called *optical groups*. The Maximum Group Area (MGA) in a flash (i.e., the area of the largest optical emission in a flash) is a useful probabilistic indicator of whether or not the flash strikes the ground. Particularly good physical insight is obtained when the LIS optical products are compared with observations from very-low-frequency/low-frequency (VLF/LF) or very-high-frequency (VHF) ground-based lightning-detection system. Since the systems observe in different parts of the electromagnetic spectrum, they all see different physical processes—and it is usually through intercomparing these datasets that the most is learned about discharge physics. Also, as noted earlier, LIS—in conjunction with other observations—will be used to better understand the mechanisms leading to terrestrial gamma-ray flashes and *transient luminous events* (TLEs[9]) associated with lightning and thunderstorms.

[9] TLEs include a variety of discharge phenomena, such as red sprites and blue jets, that occur between the top of thunderclouds and the ionosphere.

Conclusions

LIS data remain the accepted benchmark or "gold standard" for understanding global lightning climatology. Therefore, LIS on ISS will continue its cross-disciplinary support of the high-value science and applications established by the heritage OTD and LIS on TRMM missions. The project has leveraged the data-handling infrastructure (i.e., processing, archival, and distribution) from TRMM to quickly deliver high-quality LIS data to users once operations begin. ■

New Release of Chemical Kinetics and Photochemical Datasets for Use in Atmospheric Studies

Historically, NASA/Jet Propulsion Laboratory (JPL) tabulations of chemical kinetics and photochemical evaluated data have become recognized as international assets for atmospheric research aimed at understanding the interplay between changes in atmospheric composition and changes in climate. The first such compilation came out in 1972 in support of the first U.S. assessment of the environmental effects of stratospheric aircraft. Subsequent evaluations have continued to provide critical input to national and international assessment activities.

This 2015 release is the eighteenth evaluation prepared by NASA's Panel for Data Evaluation. The most recent evaluation includes comprehensive coverage of approximately 670 bimolecular reactions, 85 three-body reactions, more than 30 equilibrium constants, 225 photochemical species, 575 aqueous and heterogeneous processes, thermodynamic parameters for almost 800 species, and approximately 4500 literature citations. Each item includes recommended values (e.g., rate coefficients, absorption cross-sections, uptake coefficients) with estimated uncertainty factors and a note describing the available experimental and theoretical data together with an explanation for the recommendation. These notes contain important information that could not be conveniently tabulated.

The evaluations now include O_x, $O(^1D)$, singlet O_2, HO_x, NO_x, Organic, FO_x, ClO_x, BrO_x, IO_x, SO_x, and Na reactions, three-body reactions, equilibrium constants, photochemistry, aqueous chemistry, heterogeneous chemistry and processes, and thermodynamic parameters. In preparing *JPL 15-10*, particular emphasis was placed on critically evaluating data for:

- Reactions of singlet D oxygen [$O(^1D)$];
- Reactions of hydroxide (OH) with halocarbons;
- Reactions of sulfur compounds;
- Initial steps in isoprene oxidation;
- Photochemistry of ozone, organic compounds, and halogen oxides;
- Heterogeneous processes on liquid water, water ice, alumina, and solid alkali halide salts;
- Gas-liquid solubility (i.e., Henry's Law Constants); and
- Thermodynamic parameters (e.g., entropy and enthalpy of formation).

For those familiar with previous versions, the layout of the latest release (JPL 15-10) has been revised and improved to include with each note the full citations for the references cited within that note. In addition, complete bibliographies appear at the end of each major section of the evaluation, as does a Master Bibliography for the entire document. Hyperlinks have been added to the master tables in the Photochemistry, Henry's Law, and Thermochemistry sections to facilitate improved document navigation.

JPL 15-10 is not available in printed form but may be freely downloaded from *jpldataeval.jpl.nasa.gov* in *Adobe PDF* (Portable Data File) format. To receive email notification concerning releases of new publications, errata, website development, and mobile device applications, send a blank message to *sympa@list.jpl.nasa.gov* with "subscribe jpl-dataeval" (without quotes) in the Subject line. For more information, contact **Stanley Sander** (*Stanley.Sander@jpl.nasa.gov*) or **James Burkholder** (*James.B.Burkholder@noaa.gov*).

NASA Celebrates Earth Day in the Nation's Capital

Heather Hanson, NASA's Goddard Space Flight Center, heather.h.hanson@nasa.gov

Introduction

For the fourth year in a row, NASA teamed with Earth Day Network to celebrate Earth Day in our Nation's capitol. The event—which was open to the public—took place April 21-22 at Union Station in Washington, DC. Each year, NASA's overarching goal is to share stories with the public about how the agency uses the vantage point of space to achieve a deep scientific understanding of: our home planet; the sun and its effects on the solar system; other planets and solar system bodies; the interplanetary environment; and the universe beyond our solar system.

Activities and Presentations

NASA's Science Program Support Office (SPSO) organized and supported the two-day celebration. To kick off Earth Day on April 22, NASA Headquarters (HQ) personnel, along with representatives from other federal agencies and private organizations, took turns providing opening remarks and welcoming attendees to the celebration—see **Photo 1**. **Karena Mary Ruggiero** [Earth Day Network—*Education Director*] welcomed the participants and invited everyone to join her in shouting "Happy Earth Day!" Next, **Ellen Stofan** [NASA HQ—*Chief Scientist*] and **Michael Freilich** [NASA HQ—*Director of the Earth Science Division*] took turns explaining how the agency studies all of the planets in our solar system, why Earth is most important to us, and how and why the agency studies the Earth. Freilich closed by stating that there is no "Plan B." Therefore, we must preserve our home planet—together. **Susan Cleary** [U.S. Department of State—*Director of the Office of Policy and Public Outreach*] shared that 175 countries signed the Paris Climate Agreement on Earth Day, April 22, at the United Nations[1]. The agreement was born out of the United Nations Conference on Climate Change held in December 2015 in Paris, France[2]. **Mark Polhemus** [Union Station—*General Manager*] thanked the participants for coming to Union Station to celebrate Earth Day. **Paul Ollig** [U.S. National Park Service (NPS)—*Chief of Interpretation and Education at National Mall and Memorial Parks*] informed the participants that this year the National Park Service is celebrating 100 years of service. After talking to students about their favorite National Parks, Ollig invited everyone to repeat after him and recite the NPS Junior Park Ranger Pledge[3]. To close, **David Evans** [National Science Teachers Association—*Executive Director*] expressed the importance of studying science, technology, engineering, and mathematics (STEM) in school, and **Alicia LaRoche** [Leadership in Energy and Environmental Design® (LEED®) Green Associate—*Manager*] discussed the importance of environmental-friendly and energy-saving products.

The event offered 17 hands-on activities organized by NASA and one activity organized by the National Park

[1] Secretary of State John Kerry signed the agreement for the U.S.

[2] To learn about how NASA's SPSO supported the twenty-first Conference of Parties (COP-21) to the United Nations Framework Convention on Climate Change in Paris, France, read "Delivering NASA Science Face-to-Face to the World" in the January-February 2016 issue of *The Earth Observer* [**Volume 28, Issue 1**, pp. 20-22].

[3] The NPS Junior Park Ranger Pledge is "As a Junior Ranger, I promise to teach others about what I learned today, explore other parks and historic sites, and help preserve and protect these places so future generations can enjoy them."

Photo 1. Participants gathered in front of the NASA Hyperwall for a special 30-minute kickoff celebration. **Photo credit:** NASA

Service—see **Table 1** on page 17—that were spread throughout Union Station's Main Hall, West Hall, and outside on the West Carriage Porch. The activities on the Carriage Porch were located inside the NASA Earth Tent—see **Photo 2**. NASA's Hyperwall was set up in the Main Hall; over the two days, several NASA scientists and outreach personnel delivered more than 40 presentations—see **Photo 3**. There was also a *Tree of Thoughts* for participants to "leaf" their thoughts and experiences about how they connect with science in their daily lives—see **Photo 4**.

Approximately 2500 participants completed at least 6 hands-on activities to earn a special NASA information packet—see **Photos 5-8**. In addition, approximately 520 students from local schools participated in the event, completing several hands-on activities and watching Hyperwall presentations. It is estimated that ~20,000 others passing through Union Station witnessed the event, including a staffer from Senator Harry Reid's office and several reporters, who conducted onsite interviews with NASA scientists.

Photo 2. A Park Ranger from the U.S. National Park Service stands outside the NASA Earth Tent at Union Station on Earth Day. **Photo credit:** NASA

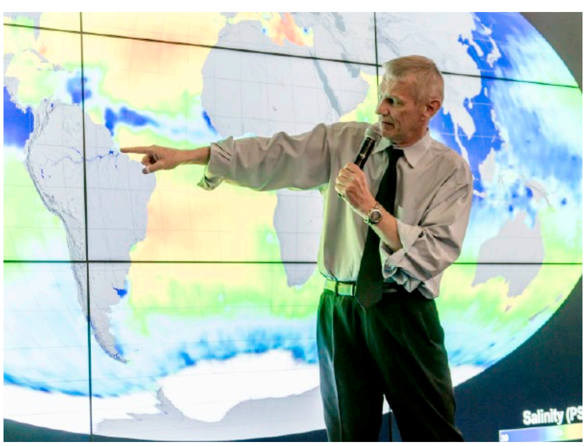

Photo 3. Astronaut **Piers Sellers** [NASA's Goddard Space Flight Center—*Deputy Director of the Science and Exploration Directorate*] delivered a Hyperwall talk titled "Help from Above." He described what it's like to be an astronaut and engage in several spacewalks. Sellers explained that his experience as a "human satellite" has led to his profound passion for studying our planet and climate change. **Photo credit:** NASA

Photo 4. At the *Tree of Thoughts*, participants were asked to share their experiences connecting science to their daily lives in the categories land, water, air, climate, weather, and life. **Photo credit:** NASA

Photo 5. Participants who visited the *Precipitation Education* station used a model of the water cycle to learn about the processes studied by the Global Precipitation Measurement mission. **Photo credit:** NASA

Photo 6. The *Dynamic Planet* allowed users to view several global datasets resulting from measurements of Earth's system components. **Photo credit:** NASA

Photo 7. Participants were thrilled to make their own cloud at the *Cloud in a Bottle* station. **Photo credit:** NASA

Photo 8. At the *Aviation and the Environment* station, participants got to see first-hand the impacts that changes in atmospheric pressure can have on marshmallow Peeps®. The Peep® on the far right shows what happens to the Peep® under extreme pressure. **Photo credit:** NASA

Table 1. Hands-on Activities at Earth Day 2016

Activity	Description
Digital Photo Booth	1-2-3, smile! NASA representatives take pictures of individual visitors, who can then walk away with a real keepsake and a cool science image from NASA.
B-Line to Space	Up, up, and away! Visitors learn how NASA balloons are used to understand the dynamics of Earth's systems.
Dynamic Planet	A touchscreen interface allows users to drive a spherical display that shows a variety of remote sensing satellite datasets.
Puzzling Changes in the Land	Visitors arrange a time series of Landsat images or piece together a Landsat scene to reveal Earth's changing landscape.
Matching Our World to Spectral Measurements	Visitors discover how NASA satellites sense the amount of light reflected from and absorbed by the surface of our planet. A graph of these data at different wavelengths is called a *spectral signature*. Visitors learn how to read these "signatures" and match them to images of different natural features.
What Color is the Ocean?	Visible light is transmitted through or absorbed by water, depending upon what's dissolved in it. Visitors measure the visible light spectrum through different-colored water samples and learn how NASA satellites use this principle to detect *chlorophyll*—the green pigment in phytoplankton.

Table 1. Hands-on Activities at Earth Day 2016 (continued)

Activity	Description
Ultraviolet Beads	NASA keeps a close eye on the sun's ultraviolet (UV) radiation. To understand how, visitors become a "UV detective" with specially designed UV-sensitive beads, and walk away with their own UV-detection bracelet.
Precipitation Education	NASA's Global Precipitation Measurement (GPM) mission measures how much it rains and snows all over the world. This display communicates the what, why, where, when, and how of this fascinating mission.
Are You a Super Sleuth? Take the Earth Imagery Challenge	NASA satellites are taking measurements of planet Earth from space. Participants follow "clues" to solve the imagery mystery.
The Dirt Under Your Shoes	Visitors learn how to take soil moisture samples to determine if soil is suitable for agriculture, or at risk for flood or drought, to demonstrate how NASA's Soil Moisture Active Passive (SMAP) satellite measures the moisture in dirt on Earth's surface.
ICESat-2 Height Challenge	Visitors learn firsthand how NASA's Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) mission will take measurements of the height of features on Earth's surface from space. They can even collect measurements similar to the satellite's using a handheld clinometer or personal cell phone.
Cloud in a Bottle	Participants help create a cloud in a bottle and learn about the important role clouds play in our atmosphere.
Searching for Other Earths with Hubble and James Webb	The first direct detection of an alien atmosphere was done with the Hubble Space Telescope in 2001. The James Webb Space Telescope will build upon Hubble's success by studying the atmospheres of Earth-sized alien worlds in infrared light. This activity explores how astronomers, using NASA's telescopes, use light and color to observe and study the universe.
Exploring Earth's Neighborhood	Visitors learn how NASA scientists are exploring Earth's nearest neighbors—the Moon, Mars, and Venus—and how these objects are similar to, and different from, our own planet.
NASA Visualization Explorer	NASA Visualization Explorer (NASA Viz) is a free iPhone, iPad, and iPod app that provides access to visualizations of current NASA research in Earth and planetary science, heliophysics, and astrophysics.
Mini-Meadows (National Park Service)	The National Park Service cares for our most precious cultural and natural resources, including pollinators like bees, birds, and butterflies. Participants can make seed balls filled with native wildflower seeds to create mini-meadows and attract these pollinators to their own front yards.
Aviation and the Environment	Earth's atmosphere protects life in many different ways. But, what would happen to us if our atmosphere suddenly disappeared? Visitors can learn how pilots and astronauts protect themselves as they travel to the very edge of Earth's atmosphere.
Eyes on the Earth 3D: Come Fly with NASA	Eyes on the Earth is a three-dimensional (3D) visualization experience that lets users "fly along" with NASA's fleet of Earth science missions and observe climate data from a global perspective in an immersive, real-time environment.

Summary

The many interactions between participants and the NASA staff that took place at Union Station gave NASA representatives the opportunity to celebrate Earth Day with individuals of all ages and from around the globe. To view more photos of the event, visit *www.flickr.com/photos/eospso/sets/72157665326277394*. NASA looks forward to celebrating Earth Day again in Washington, DC, next year. Details will be provided in a future issue of *The Earth Observer*. ■

Landsat Science Team: 2016 Winter Meeting Summary

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Introduction

The winter meeting of the joint U.S. Geological Survey (USGS)–NASA Landsat Science Team (LST) was held January 12-14, 2016, at Virginia Tech University in Blacksburg, VA. LST co-chairs **Tom Loveland** [USGS's Earth Resources Observation and Science Data Center (EROS)—*Senior Scientist*] and **Jim Irons** [NASA's Goddard Space Flight Center (GSFC)—*Landsat 8 Project Scientist*] welcomed more than 50 participants to the three-day meeting. The main objectives of this meeting focused on identifying priorities and approaches to improve the global moderate-resolution satellite record. Overall, the meeting was geared more towards soliciting team member recommendations on several rapidly evolving issues, than on providing updates on individual research activities. All the presentations given at the meeting are available at *landsat.usgs.gov//science_LST_january2016.php*.

USGS and NASA Headquarters Perspectives

Tim Newman [USGS Headquarters (HQ)—*Land Remote Sensing Program Coordinator*] and **Virginia Burkett** [USGS HQ—*Associate Director for Climate and Land Use Change*] briefed the LST on several issues pertaining to current and future Landsat missions. Both Newman and Burkett stressed the need for a concerted communications strategy to continue educating others about the benefits of Landsat and its future synergy with the European Space Agency's Sentinel-2 mission[1]. **David Jarrett** [NASA Headquarters—*Landsat Data Continuity Mission Program Executive*] informed the team that Landsat 9 is fully funded and is now optimistically slated for a 2021 launch date[2]. With the recent completion of the Sustainable Land Imaging (SLI) report, Jarrett emphasized the importance of establishing a long-term (i.e., ~20-year) vision for Landsat 10 and beyond. Although there is a strong desire to improve Landsat's capabilities, Jarrett encouraged the team to balance improving technology with the growing demand for consistent and repeatable high-frequency, moderate-resolution observations.

[1] See additional discussion of Sentinel-2 and Landsat issues beginning on page 20.

[2] The official launch date for Landsat 9 is 2021, but there is a push to be ready by 2020 in order to maximize likelihood of overlap with Landsat 7. Thus, different dates or date ranges are used in this summary depending on the specific context of the discussion.

Landsat Product Improvements: Collection Concepts

Brian Sauer [EROS—*Landsat Sustaining Engineering Project Manager*] provided an update on several new Landsat products that are currently under development at EROS. This includes a new collection-management approach that will offer more detailed labeling and versioning of all Landsat images so that users can more easily see when and what processing updates have occurred. Images will also be assigned to one of two tiers based on several quality criteria. In addition to reformatting product file names to facilitate user queries, all Landsat Thematic Mapper (TM), Enhanced Thematic plus (ETM+), and Operational Land Imager (OLI) images will also include a new quality-assessment (QA) band that will identify radiometric saturation, as well as pixels potentially contaminated with clouds, shadows, snow/ice, and water. Per-pixel solar illumination and sensor view-angle coefficients will also be disseminated starting with Collection 1. Collection 1 for Landsat 4-7 TM and ETM+ is slated for release in June 2017; Collection 1 for Landsat 8 OLI-Thermal Infrared Sensor (TIRS) will be released in November 2017. Although updates to the Landsat Multispectral Scanner (MSS) instrument will not be included in Collection 1, they will be added in future releases as issues specific to MSS images are dealt with. Overall, the LST voiced their support for the proposed changes.

John Schott [Rochester Institute of Technology] provided an update on the ongoing effort to develop and validate a Landsat global surface temperature product. Because errors increase near clouds, the data are being binned so that users can interactively decide what data are acceptable for their individual applications. In an effort to expand the approach globally, Schott's team is evaluating the use of NASA's Modern-Era Retrospective Analysis for Research and Applications (MERRA) data to correct for atmospheric effects and the use of the Moderate Resolution Imaging Spectroradiometer (MODIS[3]) Sea Surface Temperature (SST) product as a reference source for validation.

Landsat Surface Reflectance: Improving Consistency

Curtis Woodcock [Boston University—*LST Co-Leader*] made the case for improving the

[3] MODIS instruments fly onboard NASA's Terra and Aqua satellites.

consistency of surface reflectance (SR) estimates from different Landsat sensors. In particular, he discussed the three main sources of error that contribute to systematic variations in SR from different Landsat sensors. These include internal calibration (e.g., 8-bit *vs.* 12-bit data), spectral bandwidth, and sensor-specific SR-correction algorithms.

Standing in for LST member **Eric Vermote** [GSFC], **Belen Franch** [GSFC] provided an overview of the current Landsat 8 SR algorithm (referred to as L8SR). The L8SR algorithm, which is based on widely available and validated radiative transfer code, relies on MODIS Collection 6 aerosol and water vapor products to correct for atmospheric effects. While initial validation results are encouraging, some LST members voiced concerns about potential smoothing effects introduced during spatial averaging, as well as occasional occurrences of visual artifacts in areas of high relief and dense forest cover. More details on L8SR, including implementation and algorithm performance, will be available in the forthcoming Landsat 8 special issue of *Remote Sensing of Environment*.

Feng Gao [U.S. Department of Agriculture's Agricultural Research Service] described research on fusing MODIS and Landsat data to map evapotranspiration (ET). He presented results that showed similar systematic biases between Landsat 7 and 8 found by other researchers.

John Dwyer [EROS—*Landsat Project Scientist*] provided an update on the status of SR products being processed and distributed by USGS EROS. Because L8SR is still awaiting formal publication, the data released so far are considered *provisional*. The LST encouraged the USGS to increase efforts to develop and implement a single atmospheric correction algorithm that works across all Landsat sensors.

Landsat Analysis-Ready Data

Curtis Woodcock introduced the topic of Landsat Analysis-Ready Data (ARD), which offer users direct access to the highest-quality Landsat data so that landscape change can be studied with minimal independent preparation of the data. Also given that SR will form the basis of the ARD gridded, tiled, and seamless time series stacks distributed by EROS, Woodcock reiterated some of the discussion from the previous session about the urgent need to deal with atmospheric correction of SR data.

David Roy [South Dakota State University (SDSU)—*LST Co-Leader*] followed by recapping his experiences developing, producing, and distributing Web-enabled Landsat data (WELD[4]). Using the context of WELD, Roy underscored many of the challenges associated with creating operational Landsat products including the need for peer-reviewed science algorithms, standardized products, dedicated science support staff, and systematic production on dedicated computing facilities.

John Dwyer returned with an overview of the USGS definition for ARD. One of the main goals of ARD is to significantly reduce the burden of processing large data streams. Toward that end, USGS aims to offer data that have been consistently processed to the highest scientific standard. ARD will consist of both Landsat top-of-atmosphere (TOA) and SR products that are gridded, tiled, and seamlessly delivered in *Albers Equal Area projection*[5] (for the conterminous U.S.) Initial production will first focus on U.S. coverage (including Alaska and Hawaii), then will gradually expand globally, followed by the addition of Landsat MSS data. ARD will be distributed through a new application program interface; given the large amount of processing required, new acquisitions will have slightly longer latency times than past products. With increased temporal density (due to inclusion of side-lap from adjacent scenes) and newly added QA bands, ARD is poised to revolutionize the way users obtain and analyze Landsat data.

Mike Wulder [Canadian Forest Service] offered perspectives on how Landsat time series are being used to map and analyze forest disturbance and recovery dynamics across Canada. He showed how change metrics derived from Landsat time series are increasingly being used as model inputs, as well as how temporal grain and extent matter when defining change products. In addition to monitoring change, Wulder also stressed the importance of using time series to identify undisturbed forests, as they are also ecologically important.

Sentinel-2 and Landsat

Bianca Hoersch [European Space Agency (ESA)—*Sentinel-2 Mission Manager*] provided an update on ESA's Copernicus mission, including the status of the recently launched Sentinel-2A satellite[6]. She reported that Sentinel-2 data were officially released to the international user community on December 3, 2015, and that imagery are currently available for download through ESA's scientific data hub (*scihub.copernicus.eu*). So far, users have been pleased with the radiometric quality of the imagery, with many citing improved vegetation discrimination with the red-edge band and good overall alignment with Landsat spectral signatures.

[4] To learn more about WELD, visit *globalmonitoring.sdstate.edu/projects/weld*.

[5] The Albers Equal Area (conic) projection system uses two standard parallels; it shows areas accurately, but distorts shapes. Both the USGS and U.S. Census Bureau make use of this projection.

[6] ESA's Sentinel-2 mission is a land-monitoring constellation consisting of two satellites. The first, Sentinel-2A, launched in June 2015; Sentinel-2B is scheduled to launch in mid-2016. Both satellites carry the MultiSpectral Imager (MSI), which produces images with resolution similar to those obtained by OLI onboard Landsat-8.

Ferran Gascon [ESA] reported on Sentinel-2 data quality[7]. Initial analysis indicates that the signal-to-noise ratio (SNR) measured with the diffuser onboard Sentinel-2's MultiSpectral Instrument (MSI) is exceeding prelaunch mission requirements. Although some minor misregistration problems have been reported for bands 11 and 12, the overall geometric quality of the data appears to be good. Gascon also noted that improvements to the Global Reference Image (GRI), which should be completed by the summer of 2017, ought to reduce geolocation errors to 7-8 m (~23-26 ft).

Jeff Masek [GSFC—*Landsat 9 Project Scientist*] provided an update on NASA's experience with Sentinel-2A data. Masek said NASA is currently exploring the possibility of producing seamless, near-daily, 30-m (~98-ft) surface reflectance records from Landsat and Sentinel-2 data. This effort, known as the Harmonized Landsat-Sentinel (HLS) project, is a collaborative venture among GSFC, the University of Maryland, and NASA's Ames Research Center. Implemented on the NASA Earth Exchange (NEX), a data cube processing system (analogous to ARD, described above) is being developed for a limited set of test sites. The plan is to release four products [MSI SR 10-m (~33-ft), MSI SR 30-m, OLI SR 30-m, and 5-day composites, based on a best-pixel approach] for users to evaluate. Masek noted that if demand is high enough, this could become a future operational product.

David Roy briefed the LST on his initial findings prototyping a Landsat 8/Sentinel-2 global burned-area product. He said the burn-detection algorithm being developed can be used interchangeably with Landsat 8 and Sentinel-2 data. Initial results in Africa appear promising when compared with the MODIS burned-area product (i.e., *MOD45*). Due to Sentinel-2's wider swath width, Roy stressed the importance of correcting for bidirectional reflectance distribution function (BRDF) effects. He also noted a few areas of concern, including the presence of random data gaps in the Sentinel-2 images and an apparent misregistration between Sentinel-2 and Landsat 8.

Jim Storey [EROS—*Landsat Geometric Calibration Scientist*] provided an assessment of Sentinel-2's geometric image-registration and band-registration accuracy. To examine performance of Sentinel-2 the MSI Level-1C data were processed for compatibility with Landsat 8 geometric characterization tools. Comparison with USGS Global Land Survey (GLS) ground control points (GCPs) showed that Sentinel-2/Landsat 8 registration accuracy was well within Landsat data requirements. Due to differences in ground control (i.e. GLS versus GRI), Storey cautioned that misregistration between Landsat 8 and Sentinel-2 would likely persist until ESA completes the GRI update slated for the summer of 2017.

Brian Markham [GSFC—*Landsat Calibration Scientist*] presented preliminary results from the Landsat Calibration and Validation Team's evaluation of Sentinel-2A's on-orbit radiometric performance. He reported that MSI TOA reflectance was consistently within ±5% of vicarious measurements (both with and without ground measurements) which is at, or near, Landsat 8 requirements. From an absolute calibration perspective, Markham noted that the MSI visible and near-infrared bands are showing good stability but the shortwave infrared bands, which are on separate cold focal planes are showing a ±2% decrease in responsivity during periods when the focal plane is first warming up. Although initial results appear encouraging, he said it will likely take until the launch of Sentinel-2B in mid-2016 before Sentinel-2A's radiometric processing stream is stable enough to fully evaluate compatibility with Landsat 8.

Crystal Schaaf [University of Massachusetts Boston] discussed her team's use of Sentinel-2A data in the Landsat 8 albedo processing routine. She reported that initial albedo results from Sentinel-2A appear promising.

John Dwyer updated the LST on EROS plans to archive and distribute Sentinel-2A data. He stated that the USGS will begin downloading the data soon after the ESA international data hub is active in mid-February 2016[8].

Introduction of Jennifer Gimbel

Tom Loveland welcomed **Jennifer Gimbel** [Department of the Interior (DOI)—*Assistant Secretary for Water and Science*]. Gimbel offered several examples of how important Landsat is to the current administration, and encouraged the LST to continue doing science that will improve Landsat data both now and in the future. She also congratulated LST agency co-chair **Tom Loveland**, who was recently awarded the Distinguished Service Award (DSA)—DOI's highest civil servant award—for his career-long contributions to science, and specifically, for his role in land-use and land-cover change research and his contributions to advancing Landsat science and applications. Following this, the LST members in attendance each gave Gimbel a short (~30-second) overview of their Landsat-related research activities.

Landsat 9 Status

Del Jenstrom [GSFC—*Landsat 9 Project Manager*] gave an update to the team on the current status of Landsat 9. Working off the success of its predecessor,

[7] For more on Sentinel-2A product specifications and performance, see the technical documents at *sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-2-msi*.

[8] The USGS began distributing Sentinel-2 data in March 2016. For data access, see *eros.usgs.gov/sentinel-2*.

Landsat 9 will be a full Class-B rebuild of Landsat 8. As in previous missions, NASA is responsible for the space segment, including instrumentation and launch, and on-orbit checkout, while USGS will develop and manage the ground systems, including data collection, processing, archiving, and distribution. Jenstrom reported that funding is secure and in place, and the project has been directed to pursue a 2020 launch date. Jenstrom also noted that Landsat 9 data will have 14-bit quantization, an improvement over the 12-bit data offered by Landsat 8.

Sustainable Land Imaging and Landsat 10

Dave Jarrett provided an update on the status of the Sustainable Land Imaging (SLI) program and Landsat 10. He provided a brief overview of some of the technology studies that are underway for scoping systems innovations and potential hardware and systems upgrades for Landsat 10. Jarrett also discussed development of a FY2016 pathfinder servicing mission called RESTOR-L[9], which aims to use advanced robotic servicing to refuel and redeploy satellites to extend the life of future missions. He concluded by encouraging the LST to begin focusing on desired capabilities for Landsat 10 and beyond.

User Requirements for Land Imaging and SLI

Tim Newman briefed the LST on the current status of the Requirements, Capabilities, and Analysis for Earth Observation (RCA-EO) project. This initiative was established to identify Earth-observation solutions to meet evolving user needs, as well as to help inform and prioritize future SLI missions. Newman said the objective in FY2016 will be to focus on expanding the collection of user needs to other federal agencies outside of DOI, and to more closely engage the international community in looking for gaps in data or services, which could be addressed with new products or enhanced collaboration.

Landsat 7-8 Status Update

Brian Sauer [EROS—*Landsat Sustaining Engineering Project Manager*] offered an update on the mission status of Landsats 7 and 8. Sauer reported no change for Landsat 7, which has been in orbit for 17 years. Options for extending the Landsat 7 mission, which could allow for continued operation until the launch of Landsat 9 in 2020-2021, are being explored. Sauer also mentioned that Landsat 8 TIRS data collected since November 2015 will be reprocessed and released quarterly, with full capability to be made available by April 2016[10]. Sauer also discussed the current status of the ongoing Landsat Global Archive Consolidation (LGAC) effort to repatriate data from international ground stations. For more on the LGAC effort, visit *dx.doi.org/10.1016/j.rse.2015.11.032*.

Gene Fosnight [EROS—*Landsat Data Acquisition Manager*] summarized changes in the Long Term Acquisition Plan (LTAP) that governs Landsat 7 and 8. Currently, the Landsat 7 continental model is being tuned to acquire as many quality images as possible without affecting mission length. He also discussed special requests for scenes over the Arctic and Antarctic (including off-nadir acquisitions), scenes over water (to support ocean monitoring of oil seeps and spills), and scenes at night (to monitor volcanoes, urban heat islands, and active fires).

Virginia Tech Remote Sensing Activities

Meeting host **Randy Wynne** [Virginia Tech University] and his colleagues from Virginia Tech made several presentations, showcasing a number of ongoing research projects that were of interest to the LST. They covered a wide range of topics including: urban temperature mapping, automated cloud detection, history of surface coal mining in Appalachia, statistical algorithms for mapping forest change, and an overview of on-campus high-performance computing capabilities. For more on these and other presented topics, please see the meeting presentations available on the Landsat Science Team website, as noted earlier.

Landsat MSS: Using the Full Landsat Record

Warren Cohen [U.S. Forest Service] presented the case for improving the Landsat MSS record. He showed how the birth of the environmental movement in the early 1970s gave rise to the vision of William Pecora, former Director of USGS, and his idea to use land-observing satellites to monitor our changing planet. Cohen demonstrated that despite its many issues, MSS is the only option for assessing environmental degradation prior to the early 1980s. He also discussed his team's work improving the compatibility of MSS data for use with other Landsat sensors.

Dennis Helder [SDSU] discussed his team's efforts to cross-calibrate MSS with the SDSU Modtran Atmospheric Compensation for Any-time and Any-location (SMACAA) algorithm. He also discussed the implementation of SMACAA on SDSU's cluster computing environment and progress made on processing the roughly 1.3-million MSS images in the EROS archive.

Ron Morfitt [EROS] discussed the different varieties of MSS data that have come in through the LGAC effort. He also discussed issues with radiometric and geometric quality, as well as efforts to transfer Landsat 8 reflectance back through the archive.

[9] Learn more about the plans for RESTORE-L at *ssco.gsfc.nasa.gov/restore-l.html*.

[10] As of May 23, 2016 all TIRS data has been reprocessed and is now available on-line for download.

Yongwei Sheng [University of California Los Angeles] presented results from his team's work developing an image-matching approach to orthorectifying MSS data.

Doug Bolton [University of British Columbia] encouraged the USGS to continue improving the MSS archive, which would greatly improve his work estimating post-fire regrowth dynamics in slow-growing boreal forests.

At the end of this session, the LST endorsed the need to improve the MSS record and encouraged the USGS to present improvement plans at future LST meetings.

Landsat 8 Thermal Infrared Sensor Status Update

Matt Montanaro and **Aaron Gerace** [both from Rochester Institute of Technology (RIT)] provided an update on the stray-light correction algorithm being developed for the Thermal Infrared Sensor (TIRS) on Landsat 8. Montanaro explained how stray light entering the optical path from outside the direct field of view is causing significant nonuniform banding in TIRS bands 10 and 11. In order to correct for this issue the approach being developed uses TIRS data to estimate the out of view signal based on in-scene statistics. Initial validation results based on comparison with MODIS underpass data are encouraging. Once the algorithm is finalized, all Landsat 8 TIRS data will be reprocessed and made available to the user community.

Jim Storey gave an update to the team on the status of the Landsat 8 TIRS scene select mechanism encoder anomaly, explaining how degradation of the side-A and side-B encoder electronics has impacted the ability to control the mirror that rotates the sensors field of view toward Earth. Storey noted that extensive testing is underway to ensure this issue will not affect TIRS2, which is slated for launch on Landsat 9.

Conclusion

The 2016 winter LST meeting focused on identifying a number of important priorities for improving various aspects of the Landsat program. LST members offered guidance and recommendations on development of new Landsat products, enhanced synergy with Sentinel-2, and improvement of the MSS data record. The LST also identified short- and long-term goals for enhancing the consistency of surface reflectance measurements.

The next LST meeting will be held July 26-28, 2016, at SDSU in Brookings, SD. ■

Leonardo DiCaprio Visited NASA's Goddard Space Flight Center to Discuss Earth Science

Academy Award®-winning actor and environmental activist **Leonardo DiCaprio** visited NASA's Goddard Space Flight Center (GSFC) on Saturday, April 23, 2016. During his visit, DiCaprio interviewed **Piers Sellers**, [GSFC—*Former Astronaut and Deputy Director of the Sciences and Exploration Directorate*]. The two discussed the different missions NASA has underway to study changes in the Earth's atmosphere, water, and land masses for a climate change documentary that DiCaprio has in production.

Using the NASA Hyperwall, which shows visual representations based on actual science data, DiCaprio and Sellers discussed data results from NASA's fleet of satellites in Earth's orbit. During his visit, DiCaprio also visited the facility holding NASA's James Webb Space Telescope.

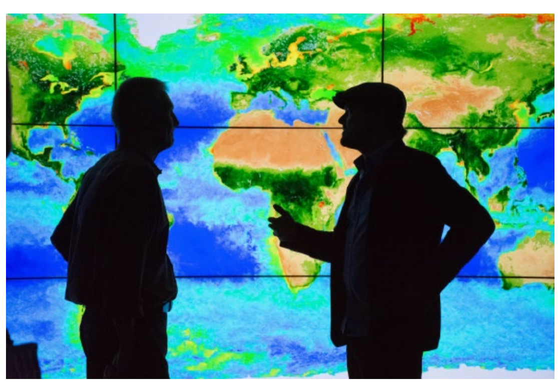

Photo credits: NASA/GSFC/Rebecca Roth

Summary of the 2016 Land-Cover Land-Use Change Regional Science Team Meeting

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Introduction

South/Southeast Asia is experiencing a population boom accompanied by rapid economic development that has had significant impacts on ecosystems in the region. A growing population requires more places to live and work, so existing agricultural areas are rapidly being converted to residential and urban areas. Said population must also be fed, which means that even more forests are being cleared and converted to agricultural fields. Dramatic increases in land-cover and land-use change (LCLUC) inevitably impact virtually all aspects of the regional ecosystem—e.g., forest resources, biodiversity, regional climate phenomena, biogeochemical cycles, and water resources. Developing appropriate and effective land-use policies is essential to sustainable development of the countries in the region.

To address these issues, the International LCLUC Regional Science Team Meeting (STM) was held January 12–18, 2016, in Yangon, Myanmar (previously known as Rangoon, Burma). This international meeting provided a forum to discuss LCLUC and its impacts with a regional focus, in the context of the emerging South and Southeast Asia Regional Initiative (SARI). The goal of SARI is to develop an innovative research, education, and capacity-building program involving state-of-the-art remote sensing, natural sciences, engineering, and social sciences, which will enrich LCLUC science in South/Southeast Asia. More details about the SARI can be found at *www.sari.umd.edu*.

NASA's LCLUC Program organized the meeting, in collaboration with the University of Maryland, College Park (UMCP), the global change SysTem for Analysis, Research and Training (START), and the international Global Observation for Forest and Land Cover Dynamics (GOFC–GOLD) Program. The president of Myanmar endorsed the meeting, with guidance from the Ministry of Environment, Conservation and Forests (MOECAF) and the Department of Geography at the University of Yangon, Myanmar, which hosted the meeting. The LCLUC STM itinerary included an optional field trip on January 12, 2016, to visit Bago, a small city located 50 miles northeast of Yangon and its environs, which is in the southwestern part of the country. During the field trip the guides and local participants discussed local LCLUC issues relating to forestry, agriculture, and urban areas—including the cultural aspects of Myanmar. To learn more, see *Field Trip to Bago—An Ancient Capital and Modern Example of LCLUC Issues in Myanmar* on the next page.

More than 150 participants from 12 different countries attended the meeting. The nations represented included India, Sri Lanka, Nepal, Thailand, Indonesia, Vietnam, Singapore, the U.S., Japan, Myanmar, Germany, and Switzerland. The meeting included scientific sessions that addressed regional and international programs in South/Southeast Asia; agriculture and water resources; forest cover mapping and monitoring; urbanization; and land-atmosphere interactions, including fires. Discussion

NASA LCLUC Myanmar meeting participants. **Photo credit:** Yangon University staff

Field Trip to Bago—An Ancient Capital and Modern Example of LCLUC Issues in Myanmar

(As told by Krishna Vadrevu)

The LCLUC STM included an optional "field trip," to Bago, the fourth largest city in the Irrawady region of Myanmar, located about 50 mi (~80 km) outside Yangon. I was among those who participated. Travelling there, I noticed how my surroundings transitioned from the dense urban center of Yangon, with its traffic congestion and pollution, to the suburban and rural landscapes outside of town, with a marked decrease in atmospheric pollution.

Bago is a region of climatological contrast. The northern region merges into a dry delta, whereas the southern region is a mixed evergreen forest, averaging more than 80 in (~203 cm) of rainfall a year. Our tour guide mentioned that most of the northern Bago hills were earlier dominated by teak and other deciduous species, whereas ironwood trees (*Xylia xylocarpa*) are common on the southern slopes. Due to the rapid deforestation and commercial exploitation of timber in the area, the forests of Bago are now highly degraded. Local residents encountered on our sojourn told us about the negative impacts of illegal logging of forests, which has been on the rise since the country opened its doors to the outside world in 1988.

The field trip to Bago was an opportunity for participants to witness firsthand some of the LCLUC issues being discussed at the meeting, such as how the landscape has been impacted by agricultural abandonment. **Photo credit:** Krishna Vadrevu

We traversed a landscape completely transformed from its native state by agriculture, with paddy rice and pulse crops dominating. We learned that most of the agricultural land is leased to farmers by the government. We were also told that, as in other parts of the world, owing to both the increasing cost and hard work required, younger residents are abandoning the farm life to pursue education and other activities in the "big city."

The environment of Bago is at risk due to the ever-increasing urban sprawl of Yangon. Poor agricultural practices have led to widespread land abandonment (see photo above for example), further exacerbating the degradation of the land surface. We noticed, for example, river banks in Bago were covered with trash.

Bago is also a major historical site, having once been the capital city of the second Myanmar Empire*. Our group visited the famous Shwemawdaw Pagoda in Bago, which, at 375 ft (114 m), is the tallest in the country. We not only got a feel for some of Bago's history, we also discovered a connection to the land, in that Buddhism is the dominant religion in the country and that Buddhist monks play a significant role in promoting environmental conservation and cultural values.

The historical sites have made tourism a significant industry for the region, but as always there is a struggle to balance economic growth and environmental degradation. Tourism in Bago has had an adverse impact on the local environment around Shwemawdaw Pagoda and the nearby Shwethalyaung reclining Buddha site—a huge statue [55-m (80-ft) long and 16-m (52-ft) tall] constructed in 994 AD. In addition, the locals spoke about a new disruption to the environment caused by ongoing construction of the new Hanthawaddy International Airport in Bago. It is due for completion by 2022, and will become Myanmar's largest and most modern airport, replacing the current Yangon International Airport. Even more urbanization can be expected once the airport is complete and operational.

Overall, the trip was highly informative. The Bago region is distinct with rich cultural history, diverse land-use types, and archaeological structures. The field trip helped us understand the local drivers of land-use change. Most importantly, we saw firsthand how urbanization, tourism, and industrial development are acting together and changing the prime agriculture and forest dominated countryside. The resulting impacts of land-use change on ecosystem functions need to be thoroughly investigated. Bago can serve as a classic example for LCLUC studies in Myanmar.

* The Taungoo Dynasty, which reigned from the mid-16th century to 1752, made Bago its capital from 1539–1599 and again in 1613–1635.

sessions followed, which addressed the needs, priorities, and challenges of land-use research in Myanmar, and regional priorities for LCLUC in South/Southeast Asia, generally. Keynote presentations, invited contributions, and a poster session were all meeting components. The meeting presentations can be downloaded from *lcluc.umd.edu/meetings/international-lcluc-regional-science-team-meeting-south-and-southeast-asia*.

The program also included two days of training for 60 national and regional scientists on the use of remote sensing and geospatial technologies at the Department of Geography, Yangon University. Specifically, the hands-on training and presentations included such topics as suitability and vulnerability analysis for urban development, long-term data processing using Landsat data, mapping regional plantation extent and dynamics using multiscale imagery, rice mapping using LIDAR data, time series analysis and forest cover change detection, and remote sensing of fires and air pollution, including atmospheric products. All participants were given certificates at the end of the training.

Opening Presentations

Pho Kaung [University of Yangon—*Rector*] welcomed participants to the meeting, followed by **Garik Gutman** [NASA Headquarters (HQ)—*LCLUC Program Manager*], who presented the SARI LCLUC science focus. He reported that deforestation in the region has been increasing, as has rapid urban expansion into rural and agricultural lands. Due to increased planting of commodity crops such as rubber and oil palm, food production has been decreasing, and with attendant cost increases. Further, conversion of land to agriculture has impacts on the carbon cycle and air-quality issues. Specific to Myanmar, forests account for 40% of the total area, but that the country is undergoing rapid deforestation due to economic development. Gutman showcased LCLUC in the Inle Lake region, and mentioned that ongoing agricultural practices are causing sedimentation, eutrophication, and loss of water in the area. He mentioned that over 200 projects on different topics have been funded since the program's inception, including LCLUC monitoring and impacts assessment, carbon-water-ecosystems, drivers, climate interactions, modeling, vulnerability, and adaptation and synthesis. Gutman stated that NASA-SARI science efforts would be based on the recent NASA Research Opportunities in Space and Earth Sciences (ROSES) LCLUC 2015 solicitation, complemented by future selections on Southeast Asia (ROSES LCLUC 2016 solicitation). Gutman closed by encouraging strengthening the SARI-SERVIR[1] relationship to achieve maximum benefit with respect to training and capacity building.

[1] SERVIR is a major NASA initiative. It means "to serve" in Spanish. See the next section for more details.


Rubber plantations along the road travelling toward the city of, Moulmein, Myanmar. **Photo credit:** Krishna Vadrevu


Degraded secondary forest near Pyin Oo Lwin, a hill town in Mandalay Division, Myanmar. **Photo credit:** Krishna Vadrevu

Chris Justice [UMCP] presented the objectives of the meeting and described why the LCLUC topic is important for the region. He stated that proper land-use management is integral to sustainable development and livelihood issues, and noted that LCLUC studies help inform land-use policy and promote better understanding of the impacts of land-use change on climate. The main objectives of the meeting, therefore, were to promote increased participation of scientists from Myanmar in the SARI initiative, understand the regional priorities for land-use science, seek out opportunities for research collaboration, understand which Earth-observation data are freely available and how to access them, share knowledge and experience on the use of Earth-observation data to study LCLUC, share experiences on effective land management practices within the region, and strengthen international scientific cooperation on land-use issues regionally and globally.

Regional and International Programs in South/Southeast Asia

Background on SARI placed the initiative in the context of previous NASA regional science initiatives focused on ecosystems and LCLUC including Boreal Ecosystem and Atmosphere Study (BOREAS), Large Scale Biosphere-Atmosphere-Experiment in Amazonia (LBA), Arctic Boreal Vulnerability Experiment (ABOVE), Southern Africa Fire and Atmospheric Research Initiative (SAFARI), Northern Eurasia Earth Science Partnership Initiative (NEESPI), and Monsoon Asia Integrated Regional Study (MAIRS). Similar to these other initiatives, SARI will aid in developing and strengthening bilateral science collaborations between the U.S. and countries in Asia and Europe, with research interests in the SARI region, enabling data collection and sharing mechanisms, and assisting in capacity building activities to utilize Earth-observation data.

Another important NASA initiative pertinent to the region is SERVIR, a program conducted jointly with the U.S. Agency for International Development (USAID), working in partnership with leading regional organizations. SERVIR brings space-based data collection to the *village level*[2] by making geospatial data useful to developing countries. The program works at the intersection of science, technology, and innovation to address the challenges of climate variability and change. The SERVIR global partners include hubs in Eastern and Southern Africa, Mesoamerica, the Himalayas, and the Mekong Basin. Each of these hubs serves countries in that region with data, analytics, training, and best practices for improved decision-making (*www.servirglobal.net/#aboutservir*). The program's focus areas include food security, weather and climate, water resources and disasters, land cover/land use, and ecosystems.

A national map system project, "OneMap Myanmar" (led by the Center for Development and Environment at the University of Bern in Switzerland), is creating an online open-access spatial data platform on land-use resources in Myanmar. Very few datasets are available for the entirety of Myanmar; thus, OneMap Myanmar is developing a one-stop portal on land use, land tenure, land use and land cover, base maps, land concessions and leases, and socioeconomic data.

The GOFC-GOLD international land-cover project office presented information on their latest project using a novel data-fusion approach to integrate two existing large-scale biomass maps into an improved pantropical, mean aboveground biomass map of woody vegetation over the period 2000 to 2013. (Additional information can be found at *www.wageningenur.nl/grsbiomass*.)

The International Center for Integrated Mountain Development (ICIMOD) has been conducting vegetation and land-use dynamics research over the Hindu Kush Himalayan region by integrating data from a number of sources including Landsat, the Japanese Advanced Land Observing Satellite (ALOS) Phased Array type L-band Synthetic Aperture Radar (PALSAR[3]), and high-resolution Google Earth images.

Additional projects include development of harmonized land-cover maps for change analysis, mapping of LCLUC drivers, forest-species mapping, time-series analysis of aboveground carbon stocks, and development of operational ground data collection frameworks to improve validation of satellite-based methodologies.

Agriculture and LCLUC

Chris Justice discussed the Group on Earth Observations, Global Agricultural Monitoring (GEOGLAM), which was endorsed by the Group of Twenty (G20) Agriculture Ministers in June 2011 in Paris, France. GEOGLAM supports reliable, accurate, timely, and sustained crop-monitoring information and yield forecasts. One of the best examples of regional coordination in Asia is the GEOGLAM Asia-Rice project (*www.asia-rice.org*). The target agricultural products include rice crop area estimates and maps, crop calendars, crop damage assessment, agrometeorological information products, production estimates, and forecasting. (Various other GEOGLAM activities can be found at *www.earthobservations.org/geoglam.php*.)

There was also a discussion of the Global Food Security Support Analysis Support Data project at 30-m resolution (GFSAD30), which is developing unbiased estimates of global agricultural cropland areas, crop types, crop watering method, and cropping intensities, using multisensor, multidate remote sensing and mature cropland mapping algorithms on data from 1990 to the present. (More details about the project, relevant datasets, and publications can be found at *geography.wr.usgs.gov/science/croplands/index.html*.) Mapping and monitoring rice ecosystems to drive decision support in the Asian region points to the potential benefits of synergistic use of data from several other orbiting platforms including Landsat, PALSAR, and the European Space Agency's Sentinel-2 mission.

This session also included an overview of the agriculture sector in Myanmar. Agriculture is the backbone of Myanmar's economy, contributing some one-fifth of its gross domestic product and total export earnings, and employing almost two-thirds of the labor force. More than 75% of the total irrigated area is used for agriculture—and this area is increasing almost yearly. Rice is the main food staple in the country, and production has been increasing; rice is also a significant export product. Although slash-and-burn agriculture is still practiced in several hilly regions of the country, several projects support land reclamation through terrace farming. Fertilizers are mostly imported from China, although use of fertilizer is relatively low compared to the other Southeast Asian countries and the world. The combination of improved seed stocks, fertilizer use, and adoption of modern technologies should allow Myanmar to continue to raise its agricultural productivity.

[2] *Village level* is considered 30-m (~98-ft) resolution—i.e., comparable to the area of a Landsat image.
[3] ALOS was launched in January 2006 into a sun-synchronous polar orbit with a 46-day repeat sycle. For more information on the ALOS PALSAR, see *www.eorc.jaxa.jp/ALOS/en/about/palsar.htm.*

Region-specific analysis leads to better understanding of the drivers of climate change in South Asia and thus makes the area less vulnerable to its impacts. In the specific case of India, for example, agricultural intensification has largely occurred through increasing the winter crop production. SARI research should focus on understanding the connections between changing economics, labor markets, and climate. Furthermore, increasing urbanization in the Asian region places agricultural areas at constant risk. For example, in Vietnam agricultural lands in and around Hanoi are increasingly fragmented, threatening the local food production capacity of *periurban*[4] areas.

LCLUC and Urban Areas

A recent study quantified LCLUC drivers in India at 30-m (~98-ft) resolution—i.e., at the village level—using Landsat imagery at decadal intervals (i.e., in 10-year windows, beginning in 1985, 1995, and 2005, respectively). The results suggest illegal forest encroachment, domestic use and subsistence activities, human pressure (e.g., roads, settlements, overgrazing, fodder extraction), and high income-generating dependence on forests as major causes of deforestation and forest degradation in the region.

In the specific case of Myanmar, the government is promoting effective land-use planning and refining land-use zoning in support of its National Land Use Policy (NLUP) formulation. During 2013, with the assistance from USAID, a roadmap for development of NLUP has been developed. The main objectives are to promote sustainable land-use management; strengthen land-tenure security; protect customary land-tenure rights of the ethnic minorities; develop transparent dispute-resolution mechanisms; encourage participatory decision making; and develop a national land law to implement NLUP. The initial phase of the NLUP lasts until early 2018. Very-high-resolution remote-sensing data are being used for NLUP decisions.

Big Data, Forests, and LCLUC

The NASA Earth Exchange (NEX[5]) provides significant utility in using *big data*[6] to explore forest characteristics and LCLUC. Global forest-cover change products with information on tree cover, forest loss, and forest gain from 2000 to 2014 at 30-m Landsat resolution are readily available. (The dataset can be downloaded from *earthenginepartners.appspot.com/google.com/science-2013-global-forest*.) Using NEX, data analysis suggests global net loss of 1.5 million km^2 (~579,000 mi^2) of forest between 2000 and 2012.

Remote sensing of wetlands—and mangroves in particular—in the Asian region is important due to their ecological, biogeochemical, and hydrological functions. About one-third of the world's mangroves are found in Asia. To learn more about this ecotype, India has attempted comprehensive mapping of its wetlands. They used data from the Indian Remote Sensing satellites for 1998, 2005, and 2012; the resulting digital atlas is available from Indian Space Research Organization (ISRO). Specific to Southeast Asia, PALSAR data have been used to map mangroves with assessments (conducted in 1990, 2000, and 2010, respectively) showing several areas of high mangrove biomass.

In Myanmar, six different institutions working under MOECAF are responsible for forestry and environmental work. The National Forest Master Plan (NFMP) covers the period from 2001 to 2031 and guides the development and implementation of forest management programs. The use of aerial photos for mapping the Irrawaddy (or Ayeyarwady) Delta mangroves goes back to the 1920s. The first recent appraisal of Myanmar's forest cover was done in 1980 under a project organized by the United Nations (UN) Food and Agriculture Organization (FAO) and the UN Environment Programme (UNEP). The challenges of forest-cover mapping in Myanmar include difficulties in procuring cloud-free images, application of automated methods to large areas, forest definition challenges, technical expertise, and funding constraints. Political activities apparently affect forest fragmentation, so the challenge for the new government lies in designing win-win policies that encourage economic and social development and ensures environmental protection.

Land-Atmosphere Interactions, Including Fires

Southeast Asia represents one of the most complex observing environments in the world due to high smoke pollution from large-scale biomass burning to clear land in the area. NASA's Seven Southeast Asian Studies (7-SEAS) mission focuses on using the synergy between satellite, aircraft, and ground-based network measurements, together with physics-based modeling, to understand interactions between aerosols, clouds, and the water cycle in Southeast Asia. Several NASA and Centre Nationale d'Études Spatiale (CNES) [the French space agency] assets are being pressed into service for this activity. These data show that Southeast Asia is among the highest contributors in the world to LCLUC-related carbon dioxide (CO_2) emissions. In addition, the Department of Meteorology and Hydrology in Myanmar collects data from meteorological, hydrological, and seismological stations spread all over the country and is responsible for processing the data and disseminating disaster-related information to the public.

[4] Periurban refers to the transition zone between urban and rural areas, where there is often conflict over how the land should be used.

[5] More details about the NEX can be found at *nex.nasa.gov/nex*.

[6] *Big data* refers to high-volume, high-velocity, and/or high-variety information assets that require new forms of processing to enable enhanced decision making, insight discovery, and process optimization. The vast information content returned from Earth-observing satellites falls into this category.

Discussion Sessions

There were two discussion sessions during the meeting. The first focused on the needs, priorities, and challenges of environmental issues specific to Myanmar; the second focused on the needs and priorities of LCLUC in the SARI region.

Needs, Priorities, and Challenges of Environmental Issues Specific to Myanmar

The first discussion session began with panelists from 10 nongovernmental organizations (NGOs) working in Myanmar. The NGOs in Myanmar are using Earth-observation data for (among other applications) natural resource assessment, land-use/land-change research, land-use planning, land tenure and rights, land-use policy, science-based conservation issues, evidence-based policy making, and sustainable management of peatlands.

After the panel exchanges, the floor was opened for discussion. All participants highlighted the need for open access to high-resolution imagery. Cloud-based internet platforms, such as Google Earth Engine, were suggested as Earth-observation data resources, and for their processing capability. Key to such efforts is the Myanmar Information Management Unit (MIMU; *www.themimu.info*), which maintains a common data repository from various sources on all sectors, countrywide, at the lowest administrative unit. In addition, OneMap Myanmar and the Mekong SERVIR projects can serve as platforms for data access and information sharing in Myanmar. Several participants from Myanmar mentioned that slow internet connectivity seriously hinders downloads.

With respect to data quality, often multiple, seemingly similar products are produced by different groups. For example, there are several products for forest cover and deforestation, and the decision on which product to use can be challenging. Stringent validation and accuracy assessments, peer review, and local expert judgment are needed to identify the highest-quality products. Cross-database standards—for definitions and classification systems—are also needed. The presentations also stressed the importance of effective communication for knowledge dissemination.

In this context, translating scientific outputs to issues that people care about (e.g., land-use change impacts on food, water, livelihoods, human well-being, and the environment) can help convey the message effectively. Panelists also encouraged the use of social media for information sharing and knowledge dissemination. Participants felt strongly about the need to collaborate more through geospatial dialogue forums and regular meetings to address environmental issues in Myanmar.

Needs and Priorities of LCLUC in the SARI Region

The second panel discussion welcomed active international participation to advance LCLUC science in the region. Of the various regional research priority areas for SARI, the emphasis has been placed on generating relevant scientific information in support of policy making in several areas. These include forest cover and change, agricultural land use and change, urban cover and change, water resources and quality, land-atmosphere interactions, land-use impacts on ecosystem services, and land-use and disaster management.

The ensuing discussion highlighted the need to move towards big-data processing to understand fine-scale changes, improve access to high-resolution Earth-observation data, involve social scientists, and develop and foster participatory approaches to address societal problems. Also, there is need for collaborative research among different government and university institutions, and an urgent need for capacity-building and training activities in the countries of the region.

Summary

The meeting served as a forum for the exchange of ideas and information from a diverse range of disciplines and interest groups. The presentations and discussions covered significant issues on the drivers and impacts of LCLUC including biophysical, social, legal, economic, political, as well as policy aspects. The training sessions were well received, and several participants expressed the need to include more such training activities in the coming years.The workshop participants acknowledged that understanding the impacts of LCLUC on the environment requires integrating both biophysical and socioeconomic datasets. They also emphasized the need to provide LCLUC related scientific information to policy makers in a timely manner to aid policy-based solutions. In addition, the workshop participants recommended increased capacity-building and training activities to advance LCLUC science in the South/Southeast Asian region.

Request for Papers on LCLUC Issues in South/Southeast Asia

As a part of meeting outputs, papers are being solicited on LCLUC issues in South/Southeast Asia, to be part of a special issue of the journal *Remote Sensing*. All researchers working on LCLUC issues in South/Southeast Asia are invited to submit articles at *www.mdpi.com/journal/remotesensing/special_issues/LCLUCAsia*. Email **Krishna Vadrevu** (*krisvkp@umd.edu*) for more details. ■

2016 CloudSat/CALIPSO Joint Science Team Meeting Summary

Todd D. Ellis, Western Michigan University, todd.ellis@wmich.edu

Meeting Overview

On April 28, 2006, the CloudSat and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) missions were launched into space onboard the same Delta-II rocket from Vandenberg Air Force Base. Today, both missions continue to operate well and produce valuable science data—to learn more see *Overview of the CloudSat and CALIPSO Missions* on page 32. *It is incredible how much science can be accomplished in ten years!* That was the running theme at the CloudSat/CALIPSO Joint Science Team Meeting, held March 1-3, 2016, in Newport, VA. This biennial gathering, attended by over 150 scientists and mission personnel, normally focuses on providing status updates to the user community and sharing and discussing new research results. However, this gathering added a decidedly celebratory feel, as both missions were approaching the tenth anniversary of their launch on April 28.

All told, there were 64 oral presentations and 59 poster presentations over the three days of the meeting. Participants enjoyed a slice of anniversary cake as they perused the poster session on the first afternoon. There were also several presentations during the meeting during which senior scientists provided a retrospective look at the trials and triumphs of the past decade while highlighting the new science continually being developed and explored by the community.

Meeting Highlights

The 2016 CloudSat/CALIPSO Joint Science Team Meeting was organized around themed sessions designed to highlight mission status, data production, and new science results from science team members. Thematic sessions included:

- Program Status Reports;
- Precipitation Processes;
- High-Latitude Processes;
- Aerosols: Direct and Indirect Effects;
- Cloud Property Retrievals; and
- Cloud, Radiation, and Storm Processes.

Every member of the CloudSat and CALIPSO science teams was required to make a presentation at the meeting. In addition, *ad hoc* breakout sessions were also held over the course of the three days in order to take full advantage of having both science teams present at the same location. There was also an update on education and communication activities related to the two missions—see *CloudSat and CALIPSO Around the GLOBE* on page 31—which are tied closely to the GLOBE program[1].

Program Status Reports

The meeting began with a series of presentations on the status of both missions. After **Graeme Stephens** [NASA/Jet Propulsion Laboratory (JPL)—*CloudSat Principal Investigator (PI)*] and **Dave Winker** [NASA/Langley Atmospheric Research Center (LaRC)—*CALIPSO PI*] welcomed everyone, **Charles Trepte** [LaRC—*Deputy PI for CALIPSO*] provided an update on CALIPSO mission status and the outlook for the mission's next two-plus years in orbit. In particular, he noted that CALIPSO had run into a on-board storage issue and had not been collecting data since January 28. This was (somewhat ironically) caused by the fact that the mission has gone significantly longer than designed, and so the time counters on the star trackers ran out of memory, thus causing cascading failures. When this is fixed, the mission is expected to have enough fuel to last at least until 2017. While the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) lasers are weakening after 5.5 billion shots, they are still functional and are also expected to last well into 2017 before backup plans are employed. **Mark Vaughan** [LaRC] then provided a detailed overview of the CALIPSO lidar data product improvements appearing in the new Version 4 products, including improved signal-to-noise ratios, improved topography data for Earth's surface, and better discrimination between clouds and aerosols.

Deborah Vane [JPL—*Project Manager for CloudSat*] and **Gregg Dombrowalski** [JPL] then provided mission and instrument updates for CloudSat, which largely focused on announcing contingencies to lessen the impacts of DO-Op mode[2] on the spacecraft. At present, while there is enough fuel for five more years of operation, the health of the heaters and the spacecraft reaction wheels are being closely monitored due to their excessive use in this mode. **Phil Partain** [CloudSat Data Processing Center, Colorado State University] provided an update to the science teams on new data products in

[1] More information on the GLOBE Program, now in its twenty-first year, can be found at *www.globe.gov.*

[2] In April 2011, CloudSat suffered a battery anomaly that forced a temporary departure from the A-Train until May 2012. Upon returning to the A-Train, battery health required the mission team to adopt Daylight-Only Operations (DO-Op) in order to restart science data collection. Thus, the mission has only collected daytime data since 2012, but is otherwise in excellent condition.

CloudSat and CALIPSO Around the GLOBE

Todd Ellis [Western Michigan University—*CloudSat Communication and Education Lead*] and **Jessica Taylor** [LaRC—*CALIPSO Communication and Education Lead*]] spoke about many of the products and resources that have been made available by the education and communication efforts of the two missions. The presentation took place on the afternoon of the third day of the meeting, and looked back over the decade of student-scientist measurements of clouds and aerosols collected around the world in connection with the GLOBE program.

The presentation was also an opportunity to bring scientists up to speed on new developments in NASA Education brought about by the 2015 Science Education Cooperative Agreement Notice and the new NASA Communications Priorities. Upcoming efforts include two-page science highlight papers that are being planned for distribution to teachers and a general public audience highlighting what we've learned, as well as *What's Up in the Atmosphere: Exploring Colors in the Sky*, which is a new Elementary GLOBE storybook about aerosols and sky color with activities appropriate for students in grades K–4. An electronic version of this book, along with connected learning activities, are located at *science-edu.larc.nasa.gov/skycolor*.

Ellis and Taylor also ran an exhibit table over the course of the meeting, with ideas for how to talk to various audiences, hands-on demonstrations, and resource materials for scientists to use to improve how they talk about clouds and aerosols when visiting with public groups.

development, including a merged Global Precipitation Mission (GPM)–CloudSat data product and a fifth edition of the base CloudSat data products that will have improved handling of surface conditions and better topographical estimates. **Mark Richardson** [JPL] briefed the meeting participants on a new joint data product, combining observations from the Orbiting Carbon Observatory 2 (OCO-2) with observations from CloudSat and CALIPSO. To close the session, **Tobias Wehr** [European Space Agency (ESA), European Space Research and Technology Center, The Netherlands] provided updates on the planned 2018 launch of the joint ESA/Japan Aerospace Exploration Agency (JAXA) Earth Cloud, Aerosol, and Radiation Explorer (EarthCARE[3]) mission.

Precipitation

The first science-themed session of the meeting focused on the structure and formation of global precipitation systems as observed by CloudSat and CALIPSO. **Angela Rowe** [University of Washington] opened the session by presenting research on the structure and frequency of occurrence of *mesoscale convective systems*—complexes of thunderstorms of various sizes and shapes that play significant roles in driving the atmospheric circulation—as they occur over the Pacific maritime continent. Other session highlights included a presentation by **Ethan Nelson** [University of Wisconsin], who presented vertical profiles from CloudSat to show where clouds release latent heat, as well as a series of presentations focused on snowfall products from CloudSat and CALIPSO. The presenters included **Guosheng Liu** [Florida State University], who used CloudSat snowfall observations to improve estimates of global snowfall from passive satellite data with better spatial and temporal coverage, and **Mark Kulie** [University of Wisconsin], who shared his group's work on understanding patterns of different snowfall events. In particular, he discussed the creation of the first census of global convective snowfall, including snow events such as lake-effect snow in the U.S.

High-Latitude Processes

The first day of the meeting concluded with a series of presentations focused on taking advantage of CloudSat and CALIPSO's unique observations of clouds and precipitation over Earth's high-latitude regions. Studying clouds and precipitation in these regions is particularly important, allowing scientists to better understand how the Arctic and Antarctic climates are changing in response to Earth's changing climate system. **Tristan L'Ecuyer**, **Elin McIlhattan**, and **Alex Matus** [all from the University of Wisconsin] used A-Train observations to show that clouds are responsible for enough downwelling longwave radiation (DLR) into the surface of Greenland to melt 90 gigatons of ice each year, with mixed-phase clouds (i.e., clouds that contain both liquid and ice) responsible for a disproportionately large portion of that energy. Using **Figure 2** on page 33, McIlhattan showed the ice-melting power of clouds over Summit Station, Greenland (72.58° N, 38.48° W) as illustrated by a comparison of DLR between A-Train observations and the Community Earth System Model-Large Ensemble (CESM-LE) project output, supported by ground-based measurements. McIlhattan and her coauthors suggest that the model bias in liquid-containing clouds (not shown) is

[3] Selected as an Earth Explorer mission under ESA's Living Planet Programme, EarthCARE is currently scheduled to launch in 2018. To learn more about the mission, please see "CloudSat, CALIPSO, and EarthCARE Science Workshop" in the March–April 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 2**, pp. 41-45], or visit *www.esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers/EarthCARE/ESA_s_cloud_aerosol_and_radiation_mission.*

Overview of the CloudSat and CALIPSO Missions

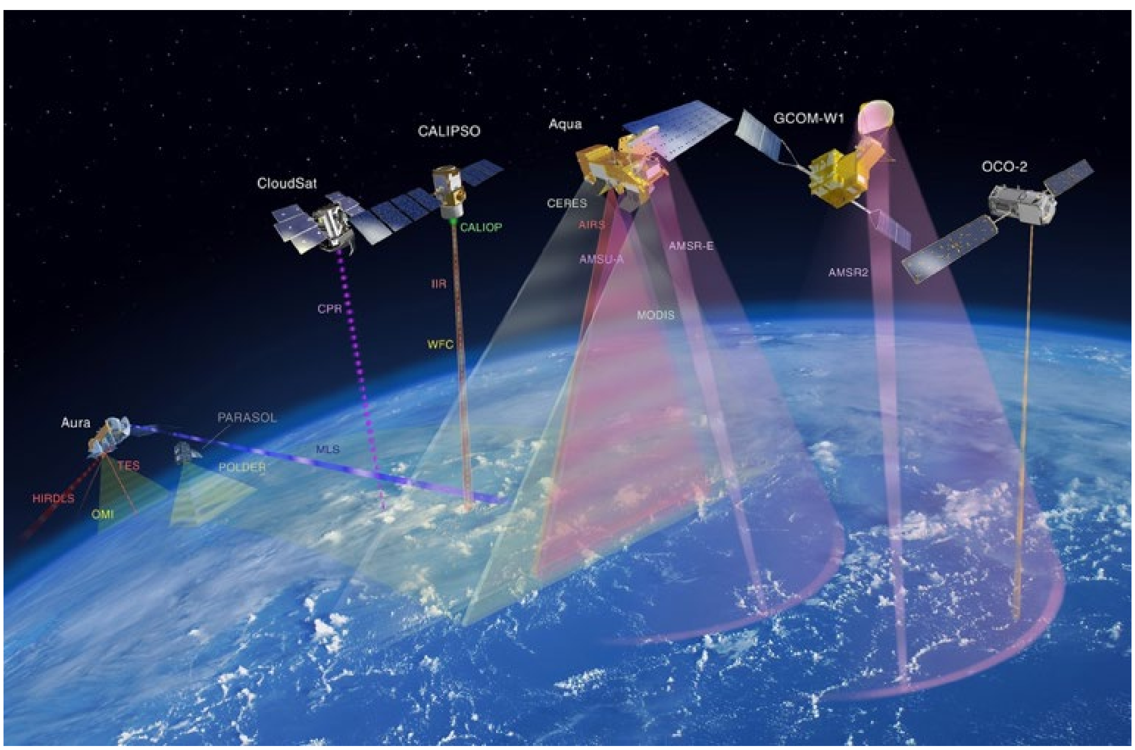
In 1998 CloudSat and CALIPSO* were both approved as separate missions that would be developed under NASA's Earth System Science Pathfinder (ESSP) Program as developmental, advanced, remote-sensing platforms designed to respond to community-identified Earth science research goals**. CloudSat has a single instrument called the Cloud Profiling Radar (CPR) that is designed to profile the vertical structure of clouds, including cloud-ice and liquid-water content. Data from CloudSat allow the science team to better understand the impacts of clouds on local and global environments, improve computer modeling of clouds and precipitation processes, and better understand the vertical distribution of heating and cooling in the Earth's atmosphere. CALIPSO has three instruments onboard: the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP), and two passive instruments: the Imaging Infrared Radiometer (IIR) and the Wide-Field Camera (WFC). Combining active and passive data helps to improve our understanding of *atmospheric aerosols*—solid or liquid particles suspended in air with diameters ranging from 0.001 to 100 µm—and their impacts on clouds and climate.

Once the two missions reached orbit, they joined the international Afternoon Constellation***, or "A-Train," which currently features a total of six operating satellites that fly in formation to collect synergistic observations of the same Earth scene within 15 minutes of each other—shown below. Both missions have well-exceeded their three-year life expectancy and are now in Extended Operations.

*CloudSat is a NASA mission, while CALIPSO is a joint NASA/Center Nationale d'Études Spatiale (CNES) [French Space Agency] mission.

** Prior to this there was a concept to have the lidar and radar on the same mission. For more background on the mission proposals that became CloudSat and CALIPSO, respectively, see "CloudSat and CALIPSO: A Long Journey to Launch…But What a Year It's Been" in the May–June 2007 issue of *The Earth Observer* [**Volume 19**, **Issue 3**, p. 7].

*** When the two missions launched in 2006, Aqua, Aura, and PARASOL were already in orbit.



This figure depicts the current configuration of the A-Train. The constellation includes NASA's Orbiting Carbon Observatory 2 (OCO-2), Aqua, CloudSat, and Aura satellites; the NASA/CNES CALIPSO satellite; and the Japan Aerospace Exploration Agency's Global Change Observation Mission – Water (GCOM-W1) satellite. The CNES-led Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a Lidar (PARASOL) mission ceased operation in 2013. The satellites cross the equator northbound at roughly 1:30 PM local time. **Image credit:** NASA

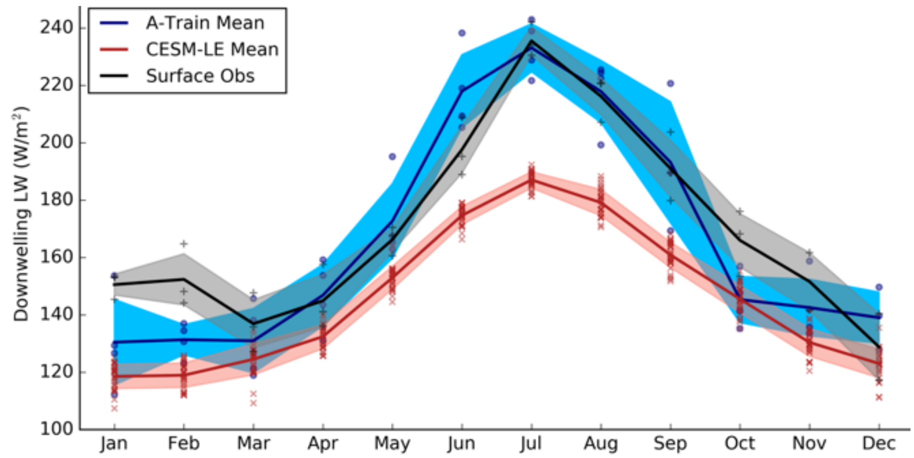


Figure 2. This figure presents monthly mean downwelling longwave radiation (DLR) from satellite observations (from the 2B-FLXHR-LIDAR data product, which combines CloudSat and CALIPSO data to infer vertical energy fluxes in the atmosphere, and is represented by blue line, 'o') and climate model outputs (CESM-LE, red line, 'x') for the period January 2007 through December 2010 over the region 70° to 75° N, 35° to 41° W. The ground observations (black line, '+') are averaged from continuous station measurements over the period January 2011 through October 2013. Solid lines show the mean monthly value, markers are individual years for the observations and ensemble members for the model, and shaded areas represent the standard deviations about the means. **Figure credit:** Elin McIlhattan; Ground observation data were taken from: Miller, N. B. *et al*. Cloud radiative forcing at Summit, Greenland. *Journal of Climate* **28**, 6267–6280 (2015).

largely responsible for this bias in infrared energy reaching the Greenland surface. **Jennifer Kay** [University of Colorado] showed that increases in cloud amount in the Arctic fall are the first direct observation of clouds responding to human-caused climate change, and that climate models still have much to do in order to get cloud properties in the polar regions to match observations.

Aerosols: Direct and Indirect Effects

Day two kicked off with a long session devoted to the satellite study of aerosols and their impacts on clouds and the radiative energy budget. It is important to note that in this context, aerosol *direct effects* refer to how aerosols themselves absorb or scatter radiant energy, while *indirect effects* refer to ways in which aerosols change the radiative properties of clouds, which in turn impact Earth's energy balance.

Highlights from this session included **Hongbin Yu** [NASA's Goddard Space Flight Center (GSFC)] showing how nearly 28 billion kg/yr of dust from Africa are transported across the Atlantic Ocean and deposited into the Amazon Basin, providing a fertilizing effect on the soils and impacting air quality in the Caribbean. **Mike Fromm** [Naval Research Laboratory] described how he used A-Train data to study how scientists can use satellites to determine the difference between volcanic ash and *pyrocumulonimbus clouds*—thunderstorm clouds that form from the smoke and water released from wildfires. **Sue van den Heever** [Colorado State University] explained how mid-latitude storm systems and hurricanes transport dust from the near surface into the upper troposphere and lower stratosphere, thereby changing the nature of where sunlight can be absorbed by these kinds of aerosols. **Robert Wood** [University of Washington] used CloudSat and CALIPSO data to show an important result regarding the prevalence of drizzle in regions of stratocumulus clouds, characterized by low numbers of aerosols and thin clouds. This result, in particular, highlighted a mode of rainfall that many climate models miss entirely in their simulations of Earth's climate system. As a whole, the results presented in this session will assist the climate community to better understand the roles clouds and aerosols play in governing the energy balance of our changing climate system.

Cloud Property Retrievals

Day three began with a series of presentations that focused on the physical properties of clouds as seen by satellites in the A-Train. Each speaker focused on a different aspect of measuring cloud liquid water and ice water by combining data from various instruments on CALIPSO and CloudSat. The highlight of this session was easily the humorous tag-team presentation of **Steve Ackerman** and **Robert Holz** [both from the University of Wisconsin]. The content of their talk focused on comparisons between cloud properties derived from Moderate Resolution Imaging Spectroradiometer (MODIS) imagery obtained by the Aqua satellite and cloud properties retrieved from CALIPSO measurements over the past ten years. Much of the talk also poked lighthearted fun at two camps of remote sensing—the passive-sensor community (i.e., MODIS) and the active-sensor community (i.e., CALIPSO and CloudSat). By highlighting the advantages and disadvantages of each type of instrument, Ackerman and Holz provided a perspective on how the remote sensing community has evolved and grown to use the best of both worlds while maintaining a friendly rivalry.

Cloud, Radiation, and Storm Processes

The final oral session of the meeting focused on the applications of A-Train observations to understanding weather and climate phenomena. **Seiji Kato** [LaRC] examined how the heating rate, temperature, and humidity profiles of clouds in historical reanalysis models need to be improved to better represent A-Train observations. **Johnny Luo** [City College of New York] presented a critical look at how scientists understand thunderstorms and how these storms move mass through the atmosphere, a key point that underpins most weather and climate model representations of thunderstorms around the world when such storms are often too small to be explicitly represented in global computer simulations. **Brian Soden** [University of Miami] showed that the extensive collection of CloudSat tropical-cyclone overpasses is a fertile resource to help improve the predictability of tropical cyclone strengthening, which is vital for predicting potential human impacts from such storms. These were but a sampling of the 20 science and applications presentations dedicated to improving various aspects of how well we understand and model important physical processes in the atmosphere, furthering our attempts to better predict weather and climate.

Summary

After ten years, CloudSat and CALIPSO are poised to continue to explore these topics as long as the satellites are flying together, which should be at least through 2017—if everything goes according to plan. In the meantime, the partnership between these two missions continues to improve what we understand about clouds, aerosols, and precipitation processes in Earth's atmosphere. After the conclusion of this year's meeting, members of the science team are looking forward to preparing for the next funding solicitation announcement from the Research Opportunities in Space and Earth Sciences (ROSES) program, and continuing to add to the hundreds of publications in anticipation of the next time the science teams will meet, sometime in 2018. ■

ASTER Data Now Available at No Charge

All data products from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument are now available at no charge. This policy change took effect April 1, 2016, and provides unlimited access to ASTER's entire over-16-year-long database. ASTER data users now have access to nearly three million individual scenes covering 99% of Earth's landmass between 83° N and S latitudes.

ASTER was launched in 1999 as one of five instruments onboard NASA's Terra satellite, and is a partnership between NASA, Japan's Ministry of Economy, Trade, and Industry (METI), Japan's National Institute of Advanced Industrial Science and Technology (AIST), and Japan Space Systems (J-spacesystems). Prior to this policy change, users could access ASTER's global digital topographic maps and some data products covering the U.S. and U.S. territories online at no charge but paid METI a nominal fee to order international ASTER data products. In announcing the change in policy, METI and NASA cited ASTER's longevity and continued strong environmental-monitoring capabilities.

ASTER data are used to create detailed maps of land-surface temperature, reflectance, and elevation, and provide critical information for surface mapping and monitoring dynamic conditions and changes over time. Applications of ASTER data include tracking glacial advances and retreats, monitoring potentially active volcanoes, identifying crop stress, determining cloud morphology and physical properties, evaluating wetlands, assessing coral reef degradation, mapping surface soil temperatures, and measuring surface heat balance.

ASTER data are processed using algorithms developed at NASA/Jet Propulsion Laboratory (JPL) and AIST, and are validated and calibrated by a joint U.S./Japan science team. "We anticipate a dramatic increase in the number of users of our data, with new and exciting results to come," says **Michael Abrams** [JPL—*ASTER Science Team Lead*].

ASTER data products are available through NASA's Land Processes Distributed Active Archive Center (LP DAAC; *lpdaac.usgs.gov/dataset_discovery/aster/aster_products_table*) located at the U.S. Geological Survey's (USGS) Earth Resources Observation and Science Center, and from AIST (*gbank.gsj.jp/madas*).

NASA's LP DAAC processes, archives, and distributes land data products to NASA-supported principal investigators, Department of Interior land managers, and Earth science data users around the world. It is 1 of 12 discipline-specific DAACs that are managed by NASA's Earth Science Data and Information System (ESDIS) Project. The ESDIS Project is part of NASA's Earth Observing System Data and Information System (EOSDIS)—a core capability in NASA's Earth Science Data Systems Program.

Carbon Dioxide Fertilization Greening Earth, Study Finds

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

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

From a quarter to half of Earth's vegetated lands has shown significant greening over the last 35 years largely due to rising levels of atmospheric carbon dioxide (CO_2), according to a new study published in the journal *Nature Climate Change* on April 25, 2016[1].

An international team of 32 authors from 24 institutions in 8 countries participated in the study, which involved using satellite data from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) and the National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer (AVHRR) instruments to help determine the *leaf area index*, or amount of leaf cover, over the planet's vegetated regions. The greening represents an increase in leaves on plants and trees equivalent in area to two times the continental U.S.—see **Figure**.

Green leaves use energy from sunlight through photosynthesis to chemically combine CO_2 drawn in from the air with water and nutrients tapped from the ground to produce sugars, which are the main source of food, fiber, and fuel for life on Earth. Studies have shown that increased concentrations of CO_2 increase photosynthesis, spurring plant growth.

However, CO_2 fertilization isn't the only cause of increased plant growth. Nitrogen, land-cover change, and climate change, by way of global temperature, precipitation, and sunlight changes, all contribute to the greening effect. To determine exactly how much CO_2 contributes, researchers ran the data for CO_2 and each of the other variables in isolation through several computer models that mimic the plant growth observed in the satellite data.

Results showed that CO_2 fertilization explains 70% of the greening effect, said co-author **Ranga Myneni** [Boston University, Department of Earth and Environment]. "The second most important driver is nitrogen, at 9%. So we see what an outsized role CO_2 plays in this process."

About 85% of Earth's ice-free land is covered by vegetation. The area covered by all the green leaves on Earth is equal to, on average, 32% of Earth's total surface area—i.e., the ocean, land, and permanent ice sheets combined. The extent of the greening over the past 35 years "has the ability to fundamentally change the cycling of water and carbon in the climate system," said lead author **Zaichun Zhu** [Peking University, China] who did the first half of this study with Myneni as a visiting scholar at Boston University.

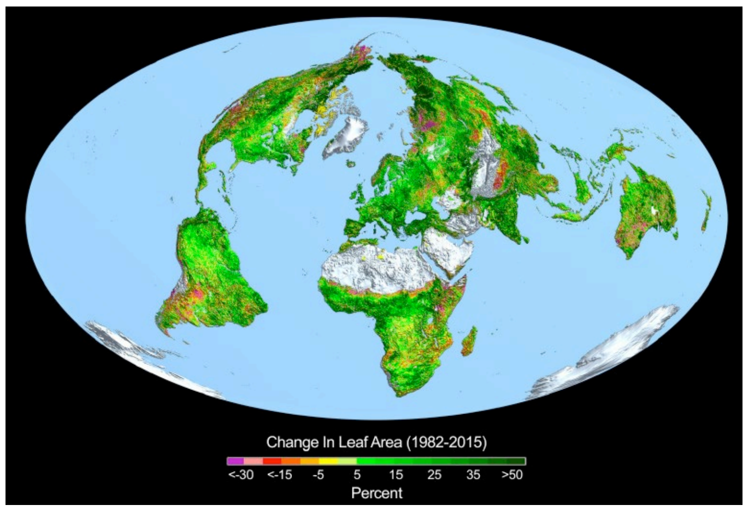


Figure. This image shows the change in leaf area across the globe from 1982-2015. **Image credit:** Boston University/Ranga Myneni

Every year, about half of the 10 billion tons of carbon emitted into the atmosphere from human activities remains temporarily stored, in about equal parts, in the ocean and plants. "While our study did not address the connection between greening and carbon storage in plants, other studies have reported an increasing carbon sink on land since the 1980s, which is entirely consistent with the idea of a greening Earth," said co-author **Shilong Piao** [Peking University, College of Urban and Environmental Sciences].

While rising CO_2 concentrations in the air can be beneficial for plants, it is also the chief culprit of climate change. The gas, which traps heat in Earth's atmosphere, has been increasing during the industrial age due to the burning of oil, gas, coal, and wood for energy and is continuing to reach concentrations not

[1] Read the paper at *www.nature.com/nclimate/journal/vaop/ncurrent/full/nclimate3004.html*.

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IceBridge Begins Eighth Year of Arctic Flights

Maria-Jose Viñas, NASA's Goddard Space Flight Center, maria-jose.vinasgarcia@nasa.gov

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

Operation IceBridge, NASA's airborne survey of polar ice, completed its first Greenland research flight of 2016 on April 19, kicking off its eighth spring Arctic campaign. This year's science flights over Arctic sea and land ice will continue until May 21.

During its seven years of operations in the Arctic, IceBridge has gathered large volumes of data on changes in the elevation of the ice sheet and its internal structure. Measurements from IceBridge have revealed a 460-mi-long (740-km-long) canyon hiding under a mile of ice and mapped the extent of a vast liquid water aquifer beneath the snow in southern Greenland. IceBridge's readings of the thickness of sea ice and its snow cover have helped scientists improve forecasts for the summer melt season and have enhanced the understanding of variations in ice thickness distribution from year to year.

This campaign's flights will be conducted onboard one of the National Oceanic and Atmospheric Administration's (NOAA) hurricane hunter planes, a P-3 *Orion*—shown in the photo below. NOAA is also providing a full crew and collecting atmospheric data during the IceBridge flights. Despite being the same type of aircraft as the one IceBridge often uses in the Arctic, the NOAA P-3 has been modified to allow it to fly into hurricanes, which made the installation of IceBridge's instruments more challenging.

"We had to adapt all of our instruments to work on the aircraft, because under the floor there's a fair amount of additional structure that we're not used to in our own P-3, and it affects what can be placed under the deck and at the ports in the belly of the plane," said **John Sonntag** [NASA's Goddard Space Flight Center (GSFC)—*IceBridge Mission Scientist*]. "It all worked out, but it required some compromises."

The plane will carry a laser altimeter to measure the elevation of sea and land ice, three types of radar instruments to study the ice layers and the bedrock underneath the ice sheet, and a high-resolution camera technology to create color maps of polar ice. Furthermore during this year's campaign, IceBridge scientists are running two types of infrared cameras to measure surface temperatures, which will allow the accurate detection of open water and *young ice*[1] thickness between sea ice floes even in flights flown during nighttime.

The first leg of the mission will be based out of Thule Air Base in northwest Greenland and out of Fairbanks, AK. Ten high-priority sea ice flights and three land flights are planned from these two sites. The sea ice flights will collect sufficient data to give scientists a good sense of how the sea ice thickness is distributed in the west Arctic basin, said **Jackie Richter-Menge** [U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory—*IceBridge Science Team Co-Lead*].

"This winter has been especially warm up in the Arctic, so there's a lot of speculation about how the summer melt is going to unfold," **Richter-Menge** said. "We know from the data IceBridge has been providing us that the sea ice thickness distribution in the Beaufort

[1] *Young ice* is defined as ice that is 10 to 30 cm (3.9 to 11.8 in) thick.

The National Oceanic and Atmospheric Administration's P-3 *Orion* airplane carrying IceBridge's scientists and instruments gets ready to take off for the Arctic campaign's first research flight from Thule Air Base, Greenland. **Photo credit:** NASA/ Operation IceBridge/John Woods

A view from the plane shows the Slidre Fiord in Eureka, Canada. **Photo credit**: NASA/Operation IceBridge/Jeremy Harbeck

Sea is very important for anticipating how the summer melt is going to go, so we want to make sure we get adequate coverage in this region to give the modelers good data to initiate their seasonal forecasts."

The second part of the Arctic campaign will be based in Kangerlussuaq, Greenland and will focus on gauging surface elevation changes in land ice.

"Our main priority is to look at the changes that have taken place since our previous campaigns, especially to look at fast-retreating glaciers like Jakobshavn and see how far inland they're melting away," said **Eric Rignot** [University of California, Irvine and NASA/Jet Propulsion Laboratory—*IceBridge Science Team Co-Lead*].

There will be seven high-priority land flights for this phase of the campaign, all of them repeats of lines that IceBridge flew during the 2015 post-melt campaign.

"By replicating most of the lines we flew in the spring and fall last year, we will look at not only yearly changes but also at seasonal changes, and this will help evaluate regional atmospheric climate models that reconstruct melt and snowfall on the ice sheet," Rignot said.

As in previous years, Operation IceBridge will cooperate with several international research initiatives. Some of the collaborations are ongoing, such as an overfly of a field site in Eureka Sound, where scientists from Environment and Climate Change Canada are collecting measurements of the depth of the snow cover over sea ice, and at least one flight under one of the lines followed by the European Space Agency's CryoSat-2 satellite. But there are also two new collaborations this year: the first is with the University of Alaska, Fairbanks. For this joint project, IceBridge will fly in a racetrack formation off the coast of Alaska to study the transition between *shore-fast ice*—sea ice attached to the coastline—and drifting ice. The second collaboration is with the recently launched European Sentinel-3 satellite[2]; weather permitting, IceBridge will fly under one or more sections of the spacecraft's orbit.

"These collaborations are important to tie our data to the big picture," said **Nathan Kurtz** [GSFC—*IceBridge Project Scientist*]. "When we fly over a group taking measurements from the ground, we can determine the accuracy of our larger, regional airborne data. Then we can extrapolate even further by combining our more detailed regional data with the large-scale coverage of the satellites."

The mission of Operation IceBridge is to collect data on changing polar land and sea ice and maintain continuity of measurements between Ice, Cloud, and land Elevation Satellite (ICESat) missions. The original ICESat mission ended in 2009, and its successor, ICESat-2, is scheduled for launch in 2018. Operation IceBridge is currently funded until 2019. The planned overlap with ICESat-2 will help scientists validate the satellite's measurements.

For more about Operation IceBridge and to follow this year's campaign, visit *www.nasa.gov/icebridge*. ■

[2] Sentinel-3A launched on February 16, 2016; it carries a suite of state-of-the-art instruments to systematically measure the temperature of Earth's oceans, land, ice and atmosphere. Plans call for Sentinel-3B to launch in 2017 and Sentinel-3C to launch in 2020.

Earth's New Lightning Capital Revealed

Molly Porter, NASA's Marshall Space Flight Center, molly.a.porter@nasa.gov

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

Earth has a new lightning capital, according to a recent study using observations from the Lightning Imaging Sensor (LIS) onboard NASA's Tropical Rainfall Measurement Mission (TRMM).

Lake Maracaibo in Venezuela earned the top spot receiving an average rate of about 233 flashes per square kilometer per year, according to the study. Researchers had previously identified Africa's Congo Basin as the location of maximum lightning activity.

The research team constructed a very-high resolution dataset derived from 16 years of space-based LIS on TRMM observations to identify and rank lightning hotspots—see **Figure** for example. They described their research in the *Bulletin of the American Meteorological Society*[1].

"We can now observe lightning flash rate density in very fine detail on a global scale," said **Richard Blakeslee** [NASA's Marshall Space Flight Center (MSFC)—*LIS Project Scientist*]. "Better understanding of lightning activity around the world enables policy makers, government agencies, and other stakeholders to make more informed decisions related to weather and climate."

Blakeslee joined forces with lightning researchers at the University of São Paulo (Brazil), the University of Maryland, the National Oceanic Atmospheric Administration, and the University of Alabama in Huntsville (UAH) to understand where and when most lightning occurs. Their findings will help forecasters and researchers better understand lightning and its connections to weather and other phenomena.

"Lake Maracaibo has a unique geography and climatology that is ideal for the development of thunderstorms," said **Dennis Buechler** [UAH].

Buechler noted that Lake Maracaibo is not new to lightning researchers. Located in northwest Venezuela along part of the Andes Mountains, it is the largest lake in South America. Storms commonly form there at night as mountain breezes develop and converge over the warm, moist air over the lake. These unique conditions contribute to the development of persistent deep

[1] The full article can be found at *journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-14-00193.1*.

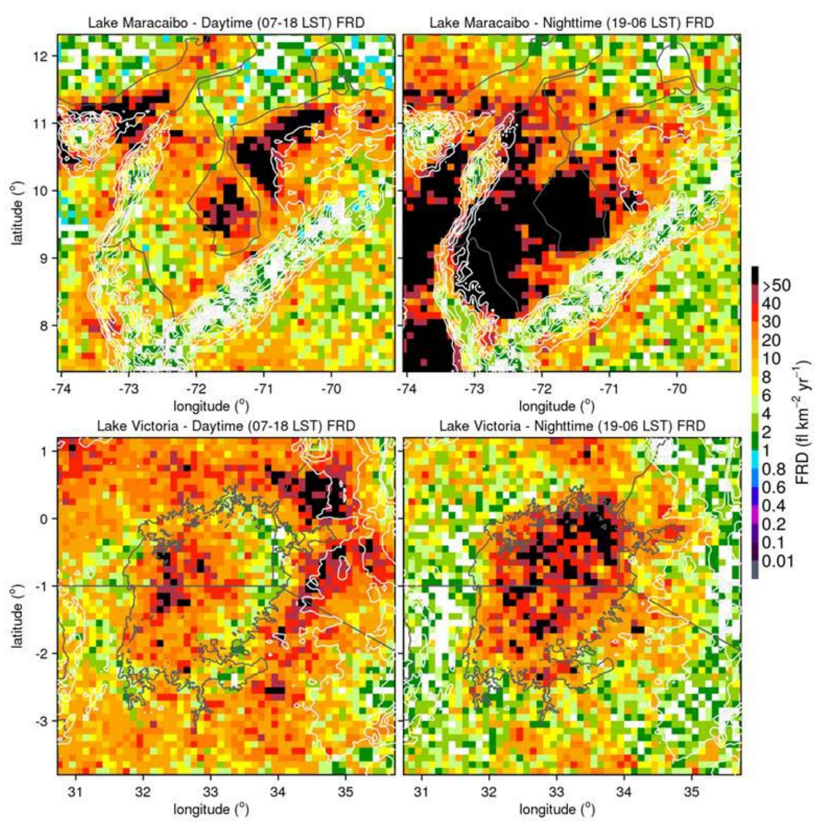

Figure: Daytime and nighttime lightning flash rate density at Lake Maracaibo in Venezuela [*top*] and Lake Victoria in Africa [*bottom*]. Note all the enhanced activity [darkest shades], particularly at night, around Lake Maracaibo, making it the new "lightning capital" of the world. White lines represent elevation, and gray lines are country physical boundaries. **Image credit**: University of São Paulo convection resulting in an average of 297 nocturnal thunderstorms per year, peaking in September.

According to the study, Africa remains the continent with the most lightning hotspots, with six of the world's top ten sites for lightning activity located there. The majority of the hotspots were by Lake Victoria and other lakes along the East African Rift Valley, which have a similar geography to Lake Maracaibo.

The study also confirmed earlier findings that concentrated lightning activity tends to happen over land and reduced lightning activity over the ocean, and that continental lightning peaks generally in the afternoon.

"Our research using LIS observations in new ways is a prime example of how NASA partners with scientists all over the world to better understand and appreciate our home planet," said Blakeslee.

Developed at MSFC, LIS detects the distribution and variability of *total lightning*—cloud-to-cloud, intracloud, and cloud-to-ground—that occurs in the tropical regions of the globe. LIS uses a specialized, high-speed imaging system to look for changes in the optical output caused by lightning in the tops of clouds. By analyzing a narrow wavelength band around 777 nm—which is in the near-infrared region of the spectrum—the sensors can spot brief lightning flashes even under bright daytime conditions that swamp out the small lightning signal.

The team at MSFC that created LIS in the mid-1990s built a spare—and now that second unit is stepping up to contribute, as well. The sensor is scheduled to launch on a Space Exploration Technologies rocket to the International Space Station in November 2016[2]. ■

Acknowledgement: The article was compiled by Ryan Connelly, an intern at MSFC.

[2] To learn more about LIS on ISS (and its predecessors), see "LIS on ISS: Expanded Global Coverage and Enhanced Applications" on page 4 of this issue.

Carbon Dioxide Fertilization Greening Earth, Study Finds

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seen in at least 500,000 years. The impacts of climate change include global warming, rising sea levels, melting glaciers, and sea ice, as well as more severe weather events.

The beneficial impacts of CO_2 on plants may also be limited, said co-author **Philippe Ciais** [Laboratory of Climate and Environmental Sciences, France—*Associate Director*]. "Studies have shown that plants *acclimatize*, or adjust, to rising CO_2 concentration and the fertilization effect diminishes over time."

"While the detection of greening is based on data, the attribution to various drivers is based on models," said co-author **Josep Canadell** [Commonwealth Scientific and Industrial Research Organisation, Australia, Oceans and Atmosphere Division]. Canadell added that while the models represent the best possible simulation of Earth system components, they are continually being improved.

Readers seeking further information can contact **Ranga Myneni** at *ranga.myneni@gmail.com*. ■

NASA Earth Science in the News

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

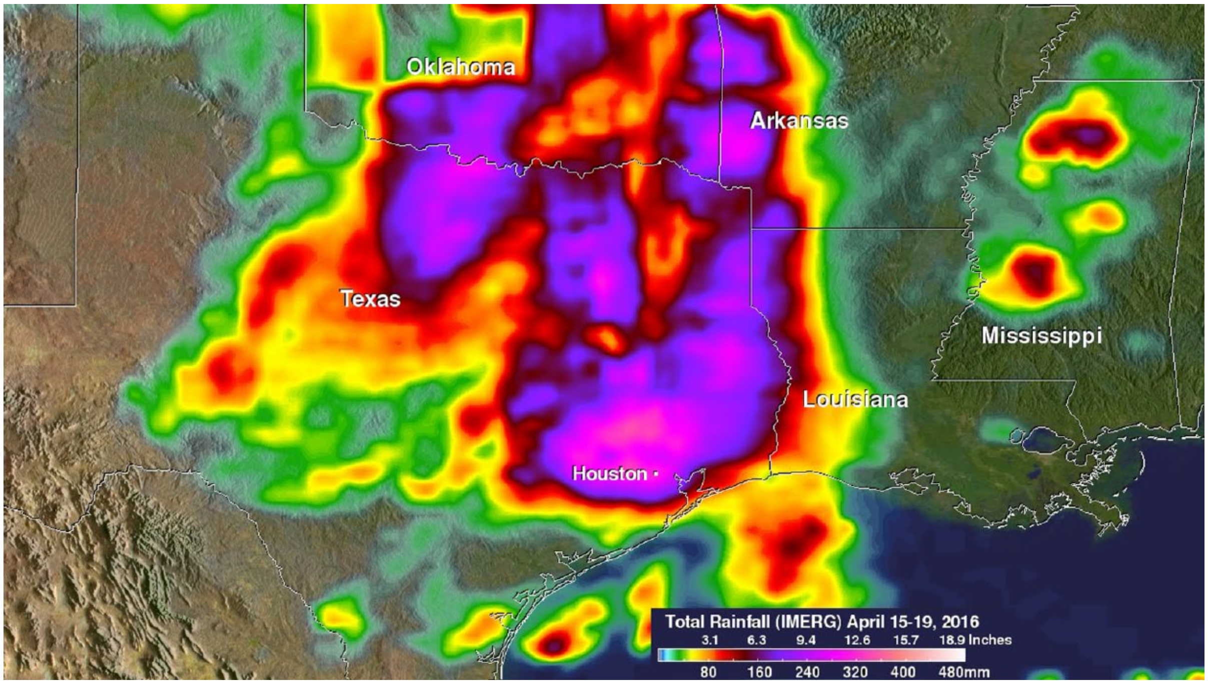
NASA Jet Gets a Sniff of Pollution over South Korea, May 9, *nature.com*. Recounting his recent experiences on a flight over South Korea, writer Mark Zastrow from *Nature* rides along on an international research mission to sample South Korean air quality: "The turbulence on this flight is intense. To take a picture I'm forced to crawl to the window, alternately wobbling on my knees and being pinned to the floor, surrounded by millions of dollars of scientific kit. But the view is worth it—I've never seen Seoul like this. Just 300 m (~984 ft) above the Han River, we are headed straight over Gangnam, one of Seoul's busiest areas, participating in one of the most comprehensive air-quality studies ever attempted. This bumpy ride means that our NASA research airplane has descended into the boundary layer, the lowest part of the atmosphere where heat and friction from the ground affect the wind and cause the air to swirl. And that means the plane is now sampling pollution from the ground that has been carried up into the air. The readings we take could help to bring some clarity to a long-standing source of tension with China—understanding how much pollution and dust drifts over from that country, and how much is homegrown in South Korea." South Korea makes for a "natural air quality laboratory," says **James Crawford** [NASA's Langley Research Center], who is the U.S. lead scientist on the international Korean air-quality study, known as KORUS-AQ. The Yellow Sea between China and the Korean peninsula acts as a natural divider, allowing scientists to measure China's pollution contributions over the water before it mixes with South Korea's air. All told, KORUS-AQ involves more than 580 researchers from 72 institutions, 3 planes, 2 ships, and 300 ground-based monitoring sites.

***NASA Announces World's New Lightning Hotspot**, May 5, *smithsonian.com*. In 1997 NASA launched the Tropical Rainfall Measurement Mission observatory, expecting the little satellite to last for three years. But the mission didn't close up shop until 2015, providing researchers many additional years of several types of climatic data beyond the focus on rainfall. Specifically, scientists have crunched the numbers from one instrument onboard the satellite, the Lightning Imaging Sensor, and recently announced that the Earth has a new top location for lightning: Lake Maracaibo, in the Andes Mountains of northwest Venezuela. With these measurements, Maracaibo now unseats the Congo Basin as the planet's flash center. According to a press release from NASA, Lake Maracaibo has been on their radar (literally) for years, but until now, no one had crunched the 16 years' worth of data. According to the study, which is published in the *Bulletin of the American Meteorological Society*[1], each square kilometer of Maracaibo experiences an average of about 233 lightning flashes a year. The thunderstorms over the lake are so frequent that sailors in the Caribbean in colonial times used the flashes as a lighthouse to keep them away from dangerous shoals.

NASA and NCAR Map Zika's Potential Spread in the U.S., April 29, *cnn.com*. Houston, we've had a problem. But, unlike the troubled Apollo 13 mission, this problem is ground based: It's a Zika-carrying mosquito. NASA scientists have helped the National Center for Atmospheric Research (NCAR) to create a map to better target future search-and-destroy missions for the deadliest animal on the planet, the female *Aedes aegypti* mosquito. The blood-sucking females are responsible for the spread of dangerous diseases such as yellow and dengue fevers, chikungunya, and now Zika. The NCAR researchers focused their analysis on 50 cities within or near to the currently known range of the *Aedes aegypti* in the U.S. The resulting map, newly released in the journal *PLOS Currents,* applies factors such as temperature, amount of rainfall, poverty levels and travel to the U.S. from Zika-affected areas of the world. The researchers also analyzed the risk for each month in the year.

***Earth Gets Greener as the Globe Gets Hotter**, April 28, *discovery.com*. Atmospheric carbon dioxide levels above historical norms has created a greener planet, a new NASA study shows. Around the world, areas that were once icebound, barren, or sandy are now covered in green foliage. All told, carbon emissions between 1982 and 2009 have fueled greening in an area about twice the size of the continental U.S., according to the study. While lush forests and verdant fields may sound like a good thing, the landscape transformation could have long-term, unforeseen consequences, the researchers say. To isolate the causes of planetary greening, researchers from around the world analyzed satellite data collected by NASA's Moderate Resolution Imaging Spectroradiometer and the National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer instruments. They then created mathematical models and computer simulations to isolate how each of these variables would be predicted

[1] The full article can be found at *journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-14-00193.1*.



NASA's Integrated Multi-satellitE Retrievals for GPM (IMERG) product is used to make estimates of precipitation from a combination of passive microwave sensors, including the microwave sensor onboard the GPM Core Observatory, and geostationary infrared data. IMERG showed heavy rainfall from April 15-19, 2016 for eastern Texas and the surrounding region. **Image credit:** NASA/JAXA/Hal Pierce

to influence greening. By comparing the models and the satellite data, the team concluded that about 70% of the greening could be attributed to increased atmospheric carbon dioxide concentrations.

Satellite Shows the Scale of Recent Deluge in Texas, April 20, *dallasobserver.com*. Every three hours a satellite called the Global Precipitation Measurement (GPM) Core Observatory records falling rain and snow, worldwide. From April 15-19, 2016, East Texas received 6-12 in (15-30 cm), with similar totals for eastern Oklahoma. Houston tallied the greatest rainfall over the measurement period, at nearly 15 in (~38 cm). "The main culprit was a stationary upper-level, low-pressure center spinning over the Central Rockies that had become detached from the main jet stream, causing it to remain in place," NASA said in a press release. The satellite, operated by NASA and the Japanese Aerospace Exploration Agency (JAXA), is the anchor of a network of satellites devoted to measuring global precipitation. Located 253 mi (407 km) above Earth in an orbit inclined 65° to the Equator, the GPM Observatory can measure precipitation daily from the Arctic Circle to the Antarctic Circle. It uses passive microwaves and radar that can generate three-dimensional profiles of rain and snow as they fall. These tallies are combined with data from other satellites in the constellation to come up with accurate totals.

In March, Earth's Temperature Deviated More from Normal than in Any Previous Month, April 19, *The Washington Post*. The planet had its eleventh straight record warm month in March 2016, but that month deviated from normal more than any that had come before, the National Oceanic and Atmospheric Administration (NOAA) reported on April 19. March's average global temperature was an unrivaled 2.20 °F above the twentieth-century average, and 0.58 °F warmer than March 2015, the previous warmest March. The month's deviation from the long-term average of 2.20 °F was 0.02 °F greater than 1,635 previous months, based on records dating back to 1880. February of this year had previously logged the biggest deviation of 2.18 °F in the NOAA analysis. According to NOAA, the current streak of 11 straight record warm months is the longest in 137 years of record keeping, They also reported that the first quarter of 2016 was, by far, the warmest on record, a full half-degree warmer than the first quarter of 2015, the previous record holder. This year (2016) is off to such a hot start that **Gavin Schmidt** [NASA's Goddard Institute for Space Studies—*Director*] estimated there is a 99% chance it will become the warmest year on record.

*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**.* ■

NASA Science Mission Directorate – Science Education and Public Outreach Update

NASA Postdoctoral Fellowships

Audience: Postdoctoral students (doctoral degree attained by the time the appointment begins).

Application Deadline: July 1, 2016

The NASA Postdoctoral Program (NPP) offers scientists and engineers unique opportunities to engage in NASA research in Earth science, heliophysics, astrophysics, planetary science, astrobiology, space bioscience, aeronautics and engineering, human exploration and operations, and space technology.

Awards: Annual stipends start at $53,500, with supplements for specific degree fields and high cost-of-living areas. There is an annual travel budget of $8000, a relocation allowance, and financial supplement for health insurance purchased through the program. Approximately 90 fellowships are awarded annually.

Eligibility: U.S. citizens, lawful permanent residents, or foreign nationals eligible for J-1 status as a research scholar may apply. Applicants must have completed a PhD or equivalent degree before beginning the fellowship, but may apply while completing the degree requirements. Fellowships are available to recent or senior-level PhD recipients.

To obtain more information and to apply for this exciting opportunity, visit *nasa.orau.org/postdoc*.

New IMAX Movie, *A Beautiful Planet,* Out Now; Related Educational Resources Available

Embark on an awe-inspiring trip around our world through the eyes of astronauts on the International Space Station (ISS) in the newly released IMAX movie, *A Beautiful Planet*. The movie stars Earth as seen from space by crewmembers onboard the orbiting laboratory. Shooting spanned multiple expeditions, and was done by NASA astronauts **Kjell Lindgren**, **Terry Virts**, and **Barry "Butch" Wilmore**, as well as former NASA astronaut **Scott Kelly**, all of whom volunteered as filmmakers during their ISS visits.

To learn more about the film and to watch a trailer, visit *www.nasa.gov/feature/window-to-earth-nasa-partners-with-imax-for-a-beautiful-planet*. Bring the excitement of *A Beautiful Planet* into your classroom! Download the educator's resource guide and supplemental activities at *IMAX.COM/ABP/Education*.

GLOBE El Niño Field Campaign and Webinar Series

El Niño and La Niña are important phenomena that can impact Earth's climate by causing global flooding and droughts as well as changes in seasonal weather. These interactions around the world are called *teleconnections*. Because of the importance of this issue, a GLOBE El Niño Southern Oscillation (ENSO) Campaign has been organized to engage students in determining where and to what extent El Niño affects local places, and to put students in direct contact with their local environments. To learn more about the campaign and how to participate, visit *www.globe.gov/web/el-nino/el-nino-campaign*.

To help educators prepare for the ENSO Campaign, GLOBE is hosting a series of free educational webinars to discuss the mechanics of the campaign, provide updates on collecting data, and give participants the opportunity to learn about relevant science from experts. The hour-long webinars will take place on the following dates at 8:00 PM EDT:

June 13, 2016: Using El Niño GLOBE Data for Scientific Research

September 19, 2016: El Niño Student Campaign Refresher and Update

For more information, including login instructions for the webinars and recordings of previous webinars in the series, visit *www.globe.gov/web/el-nino/el-nino-campaign/webinars*.

Call for Submissions—NASA Announcement for High Impact/Broad Implementation STEM Education Partnerships (EDUCATION01SP16)

The NASA Headquarters Office of Education, in cooperation with the agency's four mission directorates, nine field center education offices, and the Jet Propulsion Laboratory (JPL) education office, announces a competition to improve science, technology, engineering, and mathematics (STEM) education.

The Announcement places a priority on collaboration involving the following areas: digital learning, engaging underrepresented groups in STEM, NASA-themed STEM challenges, and youth-serving organizations. Responses must be submitted electronically via the NASA data system NSPIRES (*nspires.nasaprs.com*) by December 31, 2017. For more information about this opportunity, visit NSPIRES at *go.nasa.gov/1RZwWCi*. ■

EOS Science Calendar

June 6–10, 2016
MODIS/VIIRS Science Team Meeting
Silver Spring, MD.
modis.gsfc.nasa.gov/sci_team/meetings

June 7–10, 2016
ASTER Science Team Meeting
Tokyo, Japan.

August 30–September 1, 2016
Aura Science Team Meeting Rotterdam
The Netherlands.
aura.gsfc.nasa.gov

October 5–7, 2016
GRACE Science Team Meeting
Potsdam, Germany.
www.csr.utexas.edu/grace/GSTM

October 31–November 4, 2016
Ocean Surface Topography Science Team Meeting
La Rochelle, France.

Global Change Calendar

June 21–24, 2016
9th NASA Direct Readout Conference (NDRC-9)
Valladolid, Spain.
ndrc-9.gsfc.nasa.gov

July 31–August 5, 2016
AOGS 13th Annual Meeting, Beijing, China.
www.asiaoceania.org/aogs2016/public.asp?page=home.htm

September 1–10, 2016
IUCN World Conservation Congress
Honolulu, HI.
www.iucnworldconservationcongress.org

September 15–16, 2016
Our Ocean Conference, Washington, DC.
www.state.gov/e/oes/ocns/opa/ourocean

September 25–28, 2016
Geological Society of America Annual Meeting, Denver, CO.
www.geosociety.org/meetings

November 7–18, 2016
22nd Session of the Conference of the Parties (COP 22),
Marrakesh, Morocco.
climate-l.iisd.org/events/unfccc-cop-22

December 12–16, 2016
American Geophysical Union Fall Meeting,
San Francisco, CA.
fallmeeting.agu.org/2016

April 18–21, 2017
A-Train Symposium, Pasadena, CA.

Undefined Acronyms Used in Editorial and Table of Contents

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CALIPSO	Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations
EROS	Earth Resources Observation and Science data Center
GOES-R	Geostationary Operational Environmental Satellite–R
ICESat	Ice, Clouds, and land Elevation Satellite
ISS	International Space Station
NOAA	National Oceanic and Atmospheric Administration
TRMM	Tropical Rainfall Measuring Mission
USGS	United States Geological Survey

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

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