National Aeronautics and Space Administration

The Earth Observer. May - June 2016. Volume 28, Issue 3.

the earth observer

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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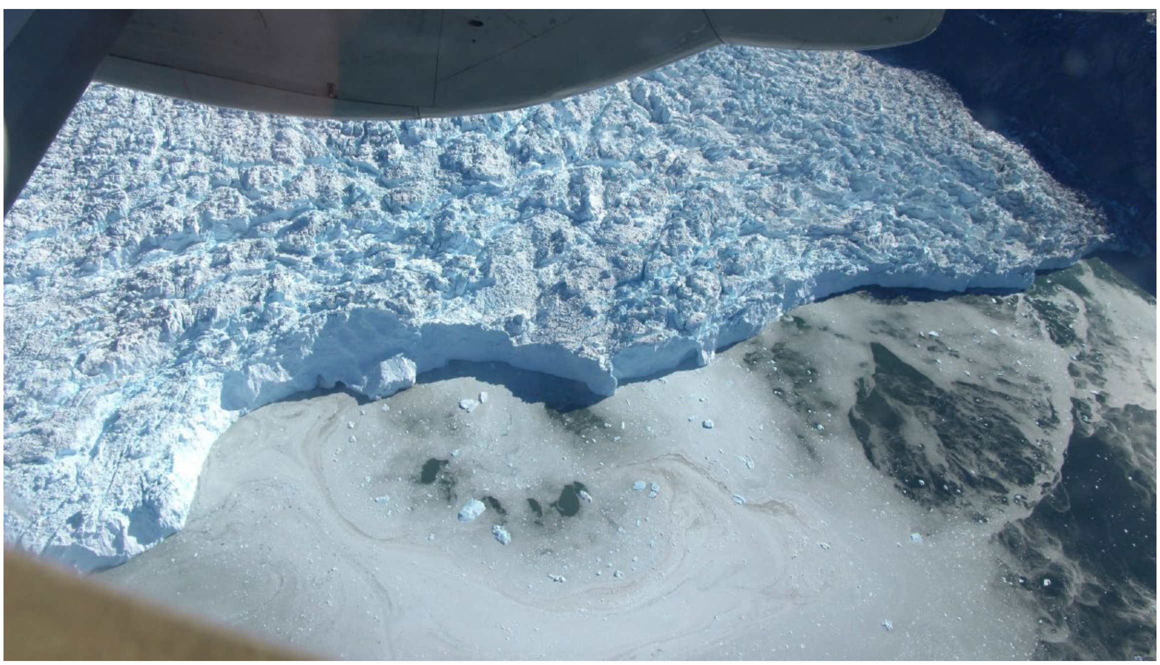

Operation IceBridge, NASA's airborne survey of polar ice, recently completed it's eighth spring Arctic campaign. This image was taken during the Umanaq B mission along Greenland's western coast. This top-down view from a NOAA P-3 aircraft shows the calving front of Sermeq Kujatdleq glacier. The aircraft's #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

In This Issue

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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.

[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].

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.

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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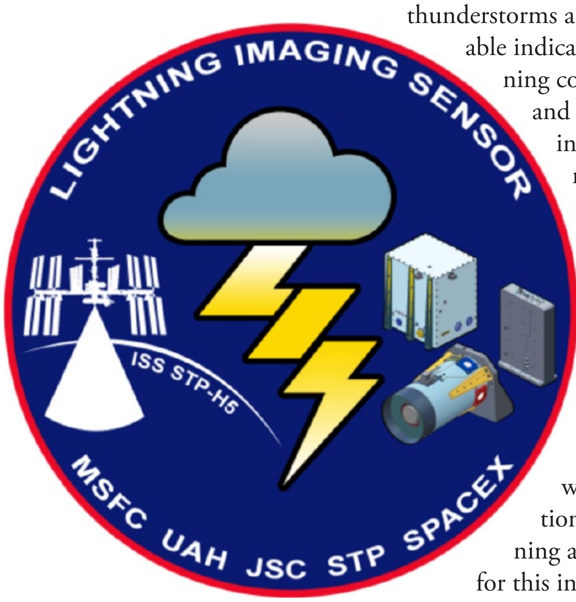
Introduction

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 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.

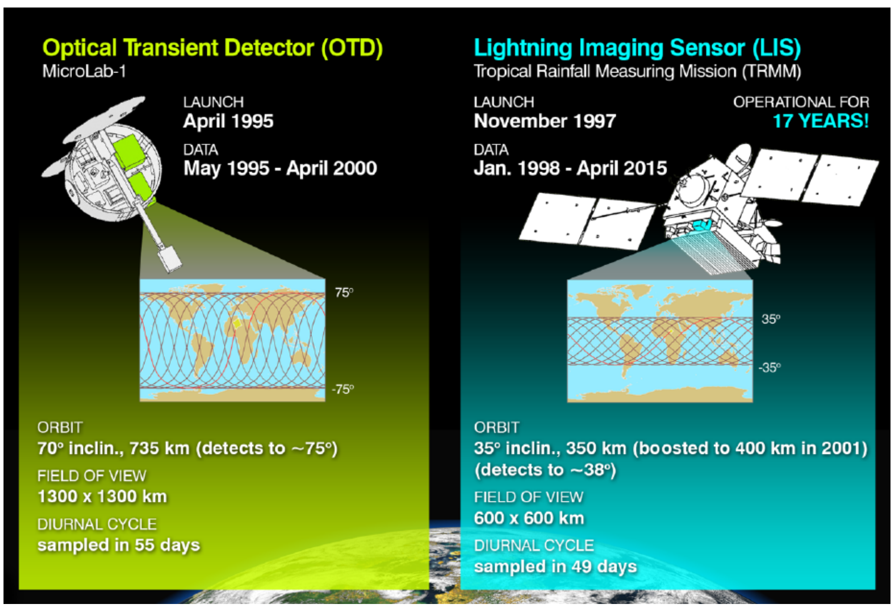


Figure 1. Since 1995, OTD and LIS on TRMM have provided 20 years of continuous combined lightning observations to create a robust global lightning climatology throughout the diurnal cycle. **Image credit:** NASA and the University of Alabama in Huntsville (UAH)

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