ISS Utilization: LIS (Lightning Imaging Sensor)

LIS (Lightning Imaging Sensor), flown on the TRMM (Tropical Rainfall Measuring Mission) of NASA (launch Nov. 27, 1997), was designed and developed at NASA/MSFC, the UA H (University of Alabama in Huntsville), and their partners. Hugh Christian of UAH is the PI (Principal Investigator) of LIS. After more than 17 years on orbit, the instrument has demonstrated successfully space-based lightning observations as an effective remote sensing tool for Earth science research and applications.

In April 2013, a space-qualified LIS built as the flight spare for TRMM, was selected for flight as a science mission on the International Space Station. The ISS-LIS will be flown as a hosted payload on the DoD STP-H5 (Space Test Program-Houston 5) mission, which is scheduled for launch in early 2016 aboard a SpaceX launch vehicle for a 2-4 year or longer mission.

The LIS measures the amount, rate, and radiant energy of total lightning over the Earth. More specifically, it measures lightning during both day and night, with storm scale resolution (~4 km), millisecond timing, and high, uniform detection efficiency, without any land-ocean bias. Lightning is a direct and most impressive response to intense atmospheric convection. It has been found that lightning measured by LIS can be quantitatively related to thunderstorm and other geophysical processes. Therefore, the ISS-LIS lightning observations will continue to provide important gap-filling inputs to pressing Earth system science issues across a broad range of disciplines, including weather, climate, atmospheric chemistry, and lightning physics.

A unique contribution from the ISS platform will be the availability of real-time lightning, especially valuable for operational applications over data sparse regions such as the oceans. The ISS platform will also uniquely enable LIS to provide simultaneous and complementary observations with other payloads such as ASIM (Atmosphere-Space Interaction Monitor) of ESA (European Space Agency) that will be exploring the connection between thunderstorms and lightning with terrestrial gamma-ray flashes (TGFs). Another important function of the ISS-LIS will be to provide cross-sensor calibration/validation with a number of other payloads, including the next generation geostationary lightning mappers, e.g., GLM (Geostationary Lightning Mapper) on GOES-R of NOAA and LI (Lightning Imager) on MTG (Melesosat Third Generation) of EUMETSAT. This inter-calibration will improve the long term climate monitoring provided by all these systems. Finally, the ISS-LIS will extend the time-series climate record of LIS lightning observations and expand the latitudinal coverage of LIS lightning to the climate significant upper middle-latitudes.

Figure 1: ISS-LIS accommodation, one of 13 instruments on the STP-H5 mission payload (image credit: DoD, NASA/MSFC)
LIS instrument preparation:

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 nearly 20 years old, its controlled storage and solid TRMM operating heritage — e.g., as of early 2015, LIS still performing well after 17 years in space — give a high degree of confidence that this flight spare will perform without problems when it is launched in early 2016 (Ref. 1).

Immediately after selection, an “aliveness” test verified that the hardware still functioned. Much more extensive functional tests and a full radiometric calibration will be completed prior to delivering the LIS in December 2014 for integration into STP-H5. The integrated package will then undergo additional testing in 2015 prior to its launch. Fortunately, many of the original scientists, engineers, and infrastructure involved with LIS development, calibration, operations and data handling, and science analysis are either still in place or still available to support pre-mission preparations and the post-launch mission and science operations. The primary mission risks faced by the project are obsolescent electronic components in the legacy LIS should a failure occur during its preparation, and the fast-track schedule that must be met.

LIS science goals and objectives:

Lightning can be quantitatively related to both thunderstorm and other geophysical processes across a broad range of disciplines, making it an effective and valuable remote sensing tool to address a variety of science and application problems facing the nation and the world. The core science goals and objectives for LIS were first defined in NASA Technical Memorandum-4350. These research objectives have continued with various refinements and augmentations since the launch of OTD (Optical Transient Detector) in April 1995 and TRMM LIS in November 1997, and they remain fully applicable for the ISS-LIS mission. At the broadest level, the LIS science goals and objectives are to acquire and investigate the global distribution and variability of total lightning and to advance the understanding of underlying and interrelated processes.

Specific research topics of scientific importance identified in NASA TM-4350 include:

1) Provide information on the total rain volume and degree of convective activity in the core regions of tropical and extra-tropical storms and storm systems, particularly as relevant to severe weather occurrence.

2) Study the global distribution of lightning and its relationship to storm microphysics and dynamics, its dependence on regional climatic environments and their changes, its relationship to precipitation and cloud type, and the incorporation of these relationships into diagnostic and predictive models of global precipitation, the general circulation and the hydrological cycle.

3) Develop global lightning climatology in order to study the distribution and variability in lightning frequency as an indicator of the intensity of the Walker and Hadley circulations and assess the impact of sea surface and land surface temperature changes on the distribution and intensity of thunderstorms, including extreme weather events.

4) Study the production, distribution, and transport of trace gases attributed to lightning and determine the contribution (and the sources of variability) to the global amount of trace gases.

5) Conduct observational and modeling studies of the global electric circuit and the factors that cause it to change. This last topic also includes investigating the relationship of lightning with ionospheric/magnetospheric processes, as
well as basic lightning physics.

Lightning measurements serve to increase knowledge of the amount, distribution, and variability of deep convection and natural sources and sinks of key trace gases on a global scale. The high temperatures attained within lightning channels provide the mechanism for the production of nitrous oxides and other trace gases. Lightning relationships are also being sought with atmospheric electrical processes such as the global electric circuit. The more recent discoveries of TLEs (Transient Luminous Events, - e.g., sprites, jets, elves) and TGFs (Terrestrial Gamma-ray Flashes) further motivates the desire for space-borne lightning measurements.

**Unique science contributions for the ISS platform:** Even though TRMM LIS has acquired a lightning climatology that now spans 17 years, there are several unique and highly valuable science benefits to be gained by also taking LIS to the International Space Station, and these represent key reasons why the LIS was selected to fly on ISS. These benefits trace to the ISS orbital characteristics – especially its higher 51.6º orbit inclination for greater global latitudinal coverage, the ISS communication advantages, and the opportunity to engage in important complementary science observations.

The first benefit is the higher latitude coverage that will be gained from the ISS as depicted in Figure 3. The TRMM LIS misses up to 30% of the lightning in the northern hemisphere in the warm season months. The ISS-LIS will detect nearly all of that lightning to enhance regional and global weather, climate, and chemistry models, studies and assessments. Also, the ISS-LIS will provide CONUS (CONtinenal US) observations needed for the NASA sponsored National Climate Assessment program.

![Lightning Flash Rate (FL yr⁻¹ km⁻³)](image_credit: NASA/MSFC)  

**Figure 3:** The maximum ISS latitude coverage of ±54.33º represents 81% of the Earth's surface, but includes 98% of the global lightning on an annual basis (image credit: NASA/MSFC)

Another unique important benefit gained from the ISS platform will be the availability of real time lightning brought down via the station's low rate telemetry channel which LIS will use. This will provide realtime lightning for operational applications in data sparse regions, especial over the oceans. It would be used to support storm forecasts and warnings, nowcasts, and oceanic aviation warnings and SIGMETs (Significant Meteorological Information). The ISS-LIS mission has been strongly endorsed by several operational partners, including the NOAA Ocean Prediction Center, Aviation Weather Center, Joint Typhoon Warning Center, and the NWS (National Weather Service) Pacific Region. The best latency that TRMM provided was on the order of 90 minutes from its quick look orbit files – the project hopes to reduce this to a few minutes or better with ISS.

Next, the ISS platform will uniquely enable ISS-LIS to provide simultaneous and complementary observations with other ISS payloads such as the ESA sponsored ASIM (Atmosphere-Space Interaction Monitor) or the JAXA (Japan Aerospace Exploration Agency) sponsored GLIMS (Global Lightning and sprite MeasurementS) missions. The combination of LIS, ASIM, and GLIMS will enable simultaneous acquisition of optical (NASA), X-ray, gamma-ray (ESA), and very high frequency or VHF (JAXA) lightning measurements that represent a unique measurement capability providing great science value, heretofore not achieved before on a single satellite platform.
Gaining a better understanding of TGFs (Terrestrial Gamma-ray Flashes) represents a prime focus of ASIM. Although a connection between TGFs and lightning/thunderstorms is apparent, a detailed understanding of the relationships remains elusive, primarily because of the lack of simultaneous TGF and lightning measurements. The LIS on ISS would be capable for the first time of observing the individual lightning strokes associated with TGF events and record this information on a millisecond time scale. The type of thunderstorm, the altitude of origin and the beaming angle of the hypothesized electron beam could then be determined, leading to a greatly improved understanding of the TGF process. The present ASIM instrument suite is incapable of detecting optical lightning events on the millisecond time scale that is required for one-to-one comparisons with TGFs. Furthermore, the conventional ASIM video cameras can only detect lightning at night, while LIS detects lightning during both day and night. This capability alone results in an 80% increase in the probability of simultaneous observations. TGFs may pose at times significant radiation hazard to aircraft pilots and passengers. This joint LIS-ASIM observation capability will advance our understanding of this threat, and, if necessary, guide mitigation strategies.

Finally, a very important function of the ISS-LIS will be to provide cross-sensor calibration/validation observations with other satellites, including the low Earth orbit TRMM LIS (if it is still in orbit in early 2016, and the prospects for this remain promising) and TARANIS (Tool for the Analysis of Radiations for Lightnings andSprites) of CNES, the next generation geostationary lightning mappers (e.g., GOES-R Geostationary Lightning Mapper and Meteosat Third Generation Lightning Imager), and even with ground-based lightning detection systems. These inter-calibrations will improve the long term climate monitoring record provided by all these systems. The ISS-LIS will extend the time-series climate record of LIS observations and expand the latitudinal coverage of LIS lightning to the climate significant upper middle-latitudes.

Launch: A launch of the DoD STP-H5 payload on the SpaceX CRS-10 (Commercial Resupply Service) Dragon cargo flight to the ISS is scheduled for Q1 2016 on a Falcon-9 vehicle from Cape Canaveral, FL. LIS is one of thirteen instruments on the STP-H5 payload manifest.

Orbit: Near-circular orbit, altitude of ~ 425 km, inclination = 51.6°.

LIS instrument description:

The legacy LIS is a small, solid state optical imager that detects lightning from LEO (Low Earth Orbit) with high detection efficiency and location accuracy, marks the time of occurrence, and measures the radiant energy. An imaging system, a focal plane assembly, a realtime signal processor and background remover, an event processor and formatter, power supply and interface electronics comprise the major elements of the sensor.

The optical and electrical elements are combined into a cylindrical sensor assembly (20 x 37 cm) and an electronics assembly (31 x 22 x 27 cm), with a total mass of approximately 20 kg, less than 30 W of power, and a telemetry data rate of only 8 kbit/s. Table 1 summarizes the overall instrument parameters and performance criteria, while Figure 5a shows the legacy LIS hardware.

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<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
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<tbody>
<tr>
<td>FOV (Field of View)</td>
<td>80° x 80°</td>
<td>Measurement accuracy:</td>
<td></td>
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<tr>
<td>PixelIFOV (Instantaneous FOV)</td>
<td>4 km</td>
<td>- Location</td>
<td>1 pixel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Intensity</td>
<td>10%</td>
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<tr>
<td></td>
<td></td>
<td>- Time</td>
<td>Tag at frame rate</td>
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Interference filter
- Wavelength: 777.4 nm
- Bandwidth: 1 nm

Dimensions
- Sensor head assembly: 20 x 37 cm
- Electronics box: 31 x 22 x 27 cm

Detection threshold: 4.7 µJ m⁻² sr⁻¹
Instrument mass: 20 kg
CCD array size: 128 x 128 pixels
Instrument power: 30 W
Dynamic range: >100
SNR (Signal to Noise Ratio): 6
Detection efficiency: ~90%
Telemetry data rate: 8 kbit/s
False event rate: <5%
Telemetry format: PCM (Pulse Code Modulation)

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<th>Table 1: LIS parameters and performance criteria</th>
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Figure 5: a) Legacy flight spare LIS the sensor assembly (left) and the electronics box (right). b) This is an advanced concept drawing showing how the Legacy LIS hardware will be mounted on the STP-H5 payload. The grey box behind the sensor assembly is the new interface unit (IFU) that will enable the legacy hardware to receive power and communications from the ISS (image credit: NASA/MSFC)

LIS operations: The LIS 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 implementing special filtering techniques in the instrument hardware to take advantage of the significant differences in the temporal, spatial, and spectral characteristics between the lightning signal and the background noise.

The design employs an expanded optics wide field-of-view lens, combined with a narrow-band interference filter, centered on the strong oxygen emission line [i.e., the oxygen multiplet at OI (Oxygen Iodine) line at 777.4 nm] in the lightning spectrum, that focuses the image on a small, high-speed 128 x 128 CCD focal plane. The final step in this process is to apply a frame-to-frame background subtraction to remove the slowly varying background signal from the raw data coming off the LIS focal plane. The signal is read out from the focal plane at 500 images per second into a real-time event processor for event detection and data compression. The resulting “lightning data only” signal is formatted, queued, and sent to the spacecraft for transmission to ground stations.

Figure 6: LIS integration as hosted payload on STP-H5 (image credit: NASA/MSFC)
ISS accommodation of LIS:

There are no significant differences in how the legacy LIS hardware is used and operates on ISS versus how it is used and operates on the TRMM platform with the minor exception of the availability of realtime data delivery. However, it is necessary to provide an additional interface unit for the ISS implementation to translate the ISS power and communications into a form that makes the ISS platform appear like the TRMM satellite to the heritage LIS electronics assembly.

Functional testing early in the ISS-LIS mission development will establish that this interface unit performs properly to pass LIS commands and science data between the LIS instrument and the ground-based operations center. Figure 5b shows the new interface unit and the mounting configuration expected on the STP-H5 payload.

The ISS-LIS will be located in a nadir viewing position. The ISS platform is presently operated at an altitude of about 425 km, which is close to that of the current TRMM mission. As such, the pixel resolution and FOV footprint on the Earth will be almost identical to that of TRMM – on the order of 4 km at nadir. On ISS, a small portion of the LIS FOV will experience obstruction as a solar panel and radiator translate through the instrument’s FOV on a predictable time schedule. An analysis has shown that the maximum mean (peak) percent obscuration that would be experienced by LIS on an orbit would be 3.6% (12.3%). This will have no impact on meeting the LIS science objectives. The OTD (Optical Transient Detector) on OrbView-1 (launch on April 3, 1995) had a permanent obstruction of similar magnitude to this peak amplitude in its FOV from its gravity gradient boom with no detrimental impact on science.

A LIS pixel, obtained from laboratory measurement, is approximately 38.94 arcmin in one dimension. It was required that temporarily fill the FIFO (First-In First-Out) data buffer of LIS. Only if the real event rate plus the false event rate (from glint in this case) exceeds the maximum LIS sustained event rate of about 300 events/s would real science data be lost. Ground-based algorithms in the LIS processing software easily identify and remove glint signals in the case where data has not been lost due to a FIFO overflow. A detailed analysis was conducted that evaluated glare from the solar panels and radiator by simulating lighting for a complete range of ISS solar beta angles from ±75º increments with images generated at one minute intervals. This analysis, for nadir or 5º off-nadir viewing, found no glare areas or fast changing illumination for either the solar panels or the radiator. This model result is consistent with an examination of a series of photos from a current ISS instrument with a similar nadir position as planned for LIS. The ISS-LIS has demonstrated that pointing close to the science team requirement is possible using ISS navigation data.

Another area of concern for the ISS-LIS is solar glare/glint. This concern traces to the fact that glint, the direct specular reflectance of sunlight into the instrument, could possibly produce an excessive amount of false detections that temporarily fill the FIFO (First-In First-Out) data buffer of LIS. Only if the real event rate plus the false event rate (from glint in this case) exceeds the maximum LIS sustained event rate of about 300 events/s would real science data be lost. Ground-based algorithms in the LIS processing software easily identify and remove glint signals in the case where data has not been lost due to a FIFO overflow. A detailed analysis was conducted that evaluated glare from the solar panels and radiator by simulating lighting for a complete range of ISS solar beta angles from ±75º increments with images generated at one minute intervals. This analysis, for nadir or 5º off-nadir viewing, found no glare areas or fast changing illumination for either the solar panels or the radiator. This model result is consistent with an examination of a series of photos from a current ISS instrument with a similar nadir position as planned for LIS. The result, along with other photographic and video examples from ISS, provide strong evidence that glint reflecting off the solar panels or the radiator will not impact ISS-LIS.

LIS on STP-H5 will be accommodated on ELC-1 (External Logistics Carrier-1) as shown in Figure 5, provided by the CBPSS (Committee on Biological and Physical Sciences in Space).

The overarching purpose of the US committee is to support scientific progress in space research in the biological, medical, and physical sciences and assist the federal government in integrating and planning programs in these fields. The scope for CBPSS spans plant and microbial biology, animal and human physiology, and basic and applied physical sciences, in the context of understanding the role of gravity in living and physical systems in order to develop capabilities required for space exploration, and using the space environment as a tool of science to advance...
knowledge. The CBPSS provides an independent, authoritative forum for identifying and discussing issues in space life and physical sciences between the research community, the federal government, and the interested public. The CBPSS will also monitor the progress in implementation of the recommendations of the RFSE (Recapturing a Future for Space Exploration): Life and Physical Sciences Research For a New Era decadal survey — building on the survey that was tasked with establishing priorities for an integrated portfolio of biological and physical sciences research in the decade of 2010-2020.

Figure 8: Accommodation of ISS science instruments (image credit: NASA, CBPSS)

Ground segment:

Core Science Applications from Lightning:

- **Weather:** Total lightning is strongly coupled in a quantitative way to thunderstorm processes and responds to updraft velocity and cloud particles (concentration, phase, type, and flux).
  - LIS acts like a radar in space: it reveals the heart of the cloud.
  - Lightning can improve convective precipitation estimates.
  - Lightning is strongly coupled to severe weather hazards (winds, floods, tornadoes, hail, wild fires) and can improve forecast models.

- **Climate:** Lightning is an excellent variable for climate monitoring because it is sensitive to small changes in temperature and atmospheric forcing. ISS LIS will:
  - Extend 16 year time series of TRMM LIS, expand to higher latitudes.
  - Monitor the occurrence and changes in extreme storms.
  - Provide much desired cross-sensor calibrations between platforms.

- **Chemistry:** ISS LIS will help improve estimates of lightning produced NOx for climate and air quality studies.
  - Lightning NOx also impacts ozone, an important green house gas.
  - Climate most sensitive to ozone in upper troposphere, exactly where lightning is the most important source of NOx.

- **Other:** Complementary ISS LIS observations will help unravel the mechanisms leading to terrestrial gamma-ray flashes (TGFs) and Transient Luminous Events (TLEs).


6) "International Space Station Research Integration and Capabilities," Committee on Biological and Physical Sciences in Space, Rod Jones Research Integration Office, October 2014, URL: [http://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/issb_152362.pdf](http://sites.nationalacademies.org/cs/groups/ssbsite/documents/webpage/issb_152362.pdf)

The information compiled and edited in this article was provided by Herbert J. Kramer from his documentation of: "Observation of the Earth and its Environment: Survey of Missions and Sensors" (Springer Verlag) as well as many other sources after the publication of the 4th edition in 2002. - Comments and corrections to this article are always welcome for further updates (herb.kramer@gmx.net).