Lightning Imaging Sensor (LIS) on the International Space Station (ISS):
Path to Attaining Level 1 Science Requirements and Early Results in Year One

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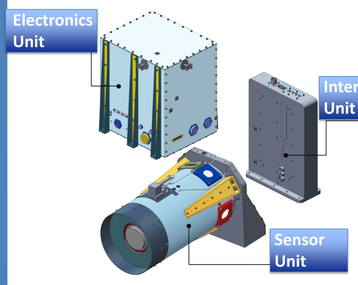
Mission and Measurement



Mission

- Fly a flight-spare LIS on ISS to take advantage of unique capabilities provided by the ISS *(e.g., high inclination, real time data)*.
- Integrate LIS as a hosted payload on the DoD Space Test Program-Houston 5 (STP-H5) mission and launch on a Space X rocket for a minimum 2 year mission.

Measurement

- NASA and its partners developed and demonstrated effectiveness and value of using space-based lightning observations as a remote sensing tool.
- LIS measures lightning (*amount, rate, radiant energy*) with storm scale resolution, millisecond timing, and high detection efficiency, with no land-ocean bias.

Sensor Unit (legacy hardware)

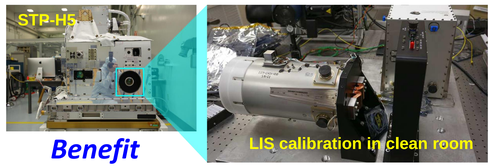
- Optical Assembly
- 128 x 128 CCD Focal Plane
- Lightning and Background detection

Electronics Unit (legacy hardware)

- Real Time Event Processor, Background removal, Data formatting
- Power conversion and control

Interface Unit (new hardware)

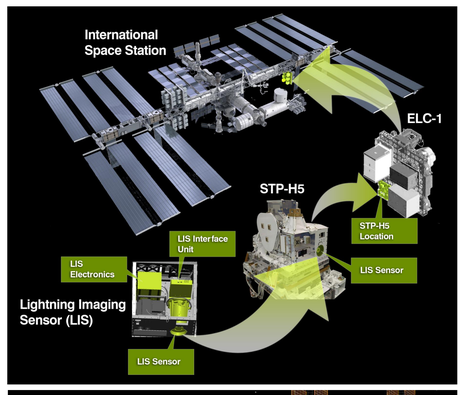
- Power conversion, timing, and control
- ISS interface

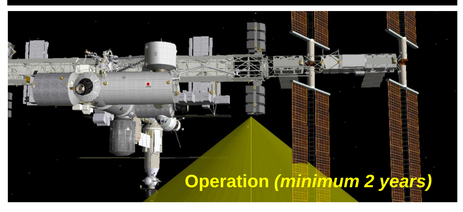


Benefit

- LIS on ISS will extend TRMM time series observations, expand latitudinal coverage, provide real time data to operational users, and enable cross-sensor calibration.

Launch, Activation, Operation, and Data Handling

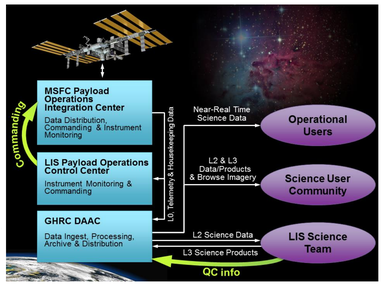




First Light !
As it appeared on the Real Time Display and Command window

- LIS launched aboard Space X Cargo Resupply Service-10 (CRS-10) mission on 19 February 2017.
- STP-H5 payload robotically installed with LIS in an Earth viewing position.
- LIS powered-up on 27 February 2017.
- Continuous operation has been maintained since LIS power-up.
- 51.6° inclination orbit, ~405 km altitude (detects to ~55°), ~ 600 x 600 km FOV.
- 60 days required for complete sample of diurnal cycle.

- The well-established and robust data handling infrastructure used for LIS on the Tropical Rainfall Measuring Mission (TRMM) was adapted for ISS.
- Therefore, lightning observations from LIS on ISS can be quickly delivered to and used by science and applications users.
- Both legacy TRMM LIS format (HDF4) and a new netCDF-4/CF data are being produced for LIS on ISS, by the Global Hydrology Resource Center, one of NASA's Distributed Active Archive Centers.
- LIS data can be obtained from the GHRC DAAC at **https://ghrc.nsstc.nasa.gov/lightning/**



Path to Attaining Level-1 Science Requirements

Level-1 Science Requirements

- Level-1 science requirements are the same for LIS on ISS as for TRMM LIS and its Optical Transient Detector (OTD) predecessor, and include (1) day and night lightning detection, (2) storm scale (~*4 km*) resolution, (3) millisecond timing, (4) high, uniform detection efficiency without land/ocean bias, (5) calibrated radiant energy, and (6) background images/intensity.
- Real time lightning data was added as an additional (7th) Level-1 requirement for LIS on ISS.
- **Identifying and associating the proper time variable *(and in some cases applying a known correction to this time)* to the science and navigation data is the most critical factor in obtaining acceptable Timing and Geolocation accuracy and stability.**

Timing Accuracy and Stability

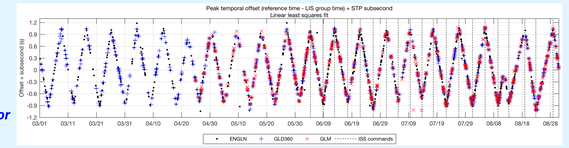
- ISS Broadcast time provided to payloads is managed manually to keep it within +/- 1 second of GPS, which would be unacceptable if it were not possible to correct.
- Fortunately, an error correction term enables time of high accuracy and stability to be obtained.

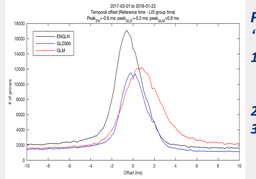
Plot on right shows time offset of LIS data time-tagged with uncorrected ISS broadcast time compared to three lightning reference "truth" sources.

Plots below show time offset following application of error correction term.

GPS Time = Broadcast Time – Time Error

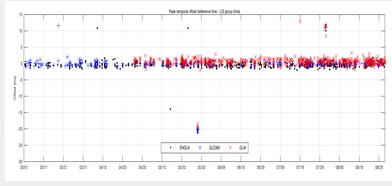
(note: correction applied in both real time and post processing)





Reference Lightning "Truth" Data Sources:

1) *Earth Networks Global Lightning Network (ENGLN)*
2) *Vaisala GLD360*
3) *Geostationary Lightning Mapper (GLM)*

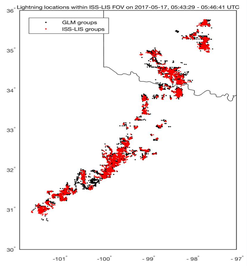


Time offset of LIS compared to the three reference sources demonstrates sub-millisecond timing accuracy.

Peak time offset of LIS to reference data in 30 second bins over six months demonstrates good time stability.

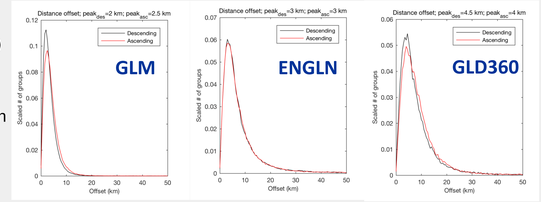
Geolocation Accuracy

- Ephemeris (position and velocity) is bundled and time-tagged with Pointing and Support (PS) Time that provides accurate GPS with no correction. Quaternion and rate variables also use PS time but require correction (***i.e., GPS Time = PS Time – Time Error***).
- Even with correct timing applied to navigation variables, peak distance offsets of 20-30 km still remained.
- Therefore, fine turning of Roll, Pitch, Yaw and Lens distortion applied to give subpixel pointing, as shown by the excellent agreement obtained between LIS and GLM during this overpass of a Texas-Oklahoma thunderstorm system in the plot to the right.



Distance offset of LIS compared with GLM ("apples – to – apples optical") shows sharp peak with sub-pixel accuracy of 2-2.5 km.

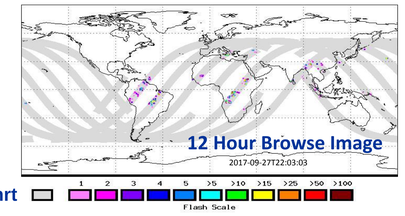
Distance offsets of LIS compared with the long-range Earth Networks and GLD360 RF systems further verifies this excellent geolocation accuracy.



Real Time Data Production

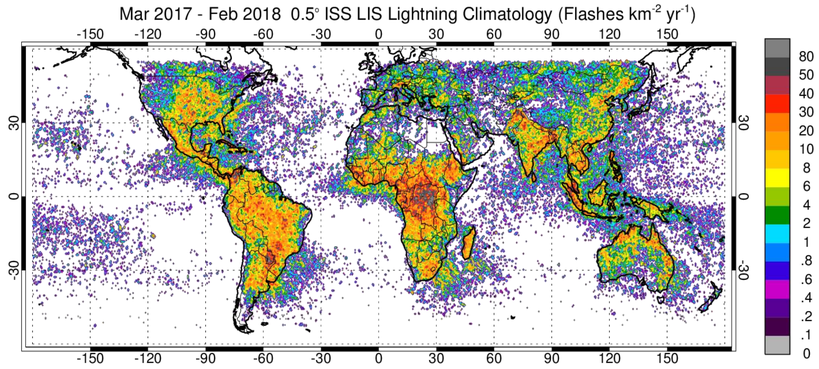
- LIS on ISS data is processed in real time in 2-minute processing increments.
- This data is available from GHRC DAAC.
- Both 2 minute and 12 hour browse images are created in real time and displayed at:

https://lightning.nsstc.nasa.gov/isslisib/isslisnrt



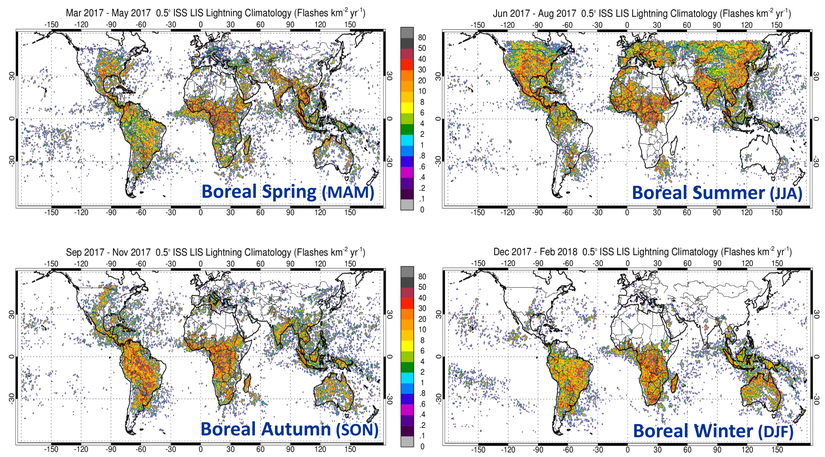
Preliminary Results in Year One

Annual Global Flash Rate



Annual global lightning flash rate (Flashes km^{2} yr^{-1}) from LIS on ISS over first year with view time and detection efficiency corrections applied. Results are similar to prior climatology. Same is true for seasonal behavior (shown below). Hint of potential lens contamination is being investigated.

Seasonal Global Flash Rate

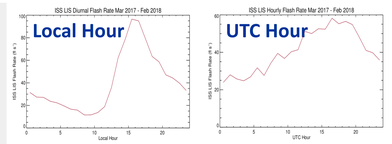


Other Preliminary Flash Statistics

One year is too short a duration to get robust statistics from low Earth orbit, but the values are consistent with the prior space-based OTD/LIS climatology.

Table shows flash rate (flashes s^{-1}) for LIS on ISS versus climatology[1].

Region	Annual	MAM	JJA	SON	DJF
World	45.7	44.1	55.7	47.2	35.9
<37.5°	40.7	40.9	42.5	42.5	34.9
LIS/ISS	41.1	39.8	52.5	41.2	30.8



Consistent Diurnal Behavior
(*will improve with multi-year sampling*)

[1]*Blakeslee et al., Atmospheric Research 135-136 (2014) 228-243*

Summary

- All Level-1 science requirements met and preliminary global flash statistic produced.
- Key science and operational applications of LIS lightning observations are being pursued that range from weather and climate to atmospheric chemistry and lightning physics.
- These applications exist due to the strong quantitative connections that can be made between lightning and other geophysical processes of interest.
- The space-based vantage point, such as provided by LIS on ISS, still remains an ideal location to obtain global lightning observations and serve as a "gold standard" measurement.