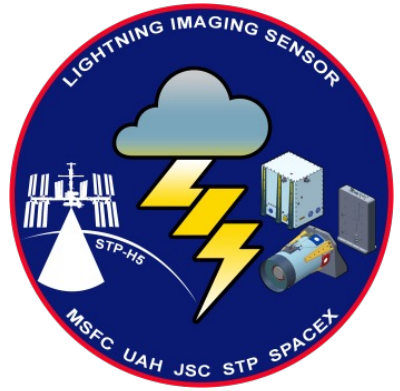
National Aeronautics and Space Administration



STO
Science & Technology Office

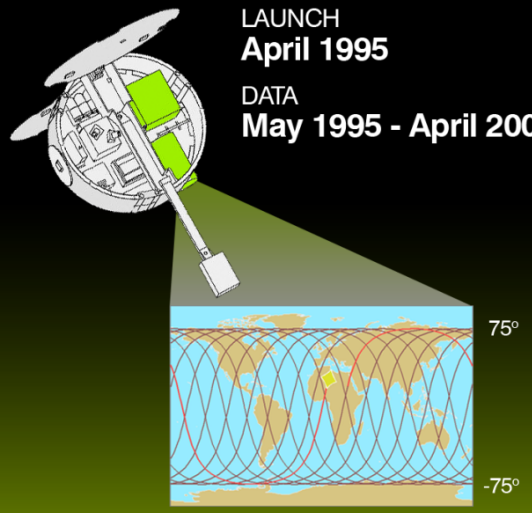
The International Space Station Lightning Imaging Sensor (ISS LIS): An overview of more than five years of science and operations, with a look toward the future of spaceborne lightning observations

Timothy Lang
Lead Research AST, Earth Science Branch

With contributions from: Sarah Bang, Phil Bitzer, Rich Blakeslee, Shannon Brown, Dennis Buechler, Dan Cecil, Austin Clark, Ken Cummins, Shing Fung, Patrick Gatlin, Steve Goodman, Burcu Kosar, Bill Koshak, Scott Lindstrom, Chuntao Liu, Doug Mach, Torsten Neubert, Nikolai Østgaard, Robert Plunkett, Mason Quick, Chris Schultz, Leigh Sinclair, Geoffrey Stano, Sarah Stough, Katrina Virts, Dan Walker, Yuling Wu, Daile Zhang, Yanan Zhu

ISS LIS – THE MISSION

Optical Transient Detector (OTD)
MicroLab-1



LAUNCH
April 1995

DATA
May 1995 - April 2000

ORBIT
70° inclin., 735 km (detects to ~75°)

FIELD OF VIEW
1300 x 1300 km

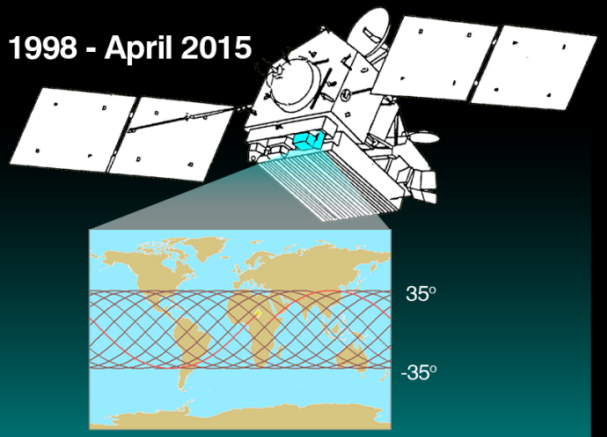
DIURNAL CYCLE
sampled in 55 days

Lightning Imaging Sensor (LIS)
Tropical Rainfall Measuring Mission (TRMM)

LAUNCH
November 1997

OPERATIONAL FOR
17 YEARS!

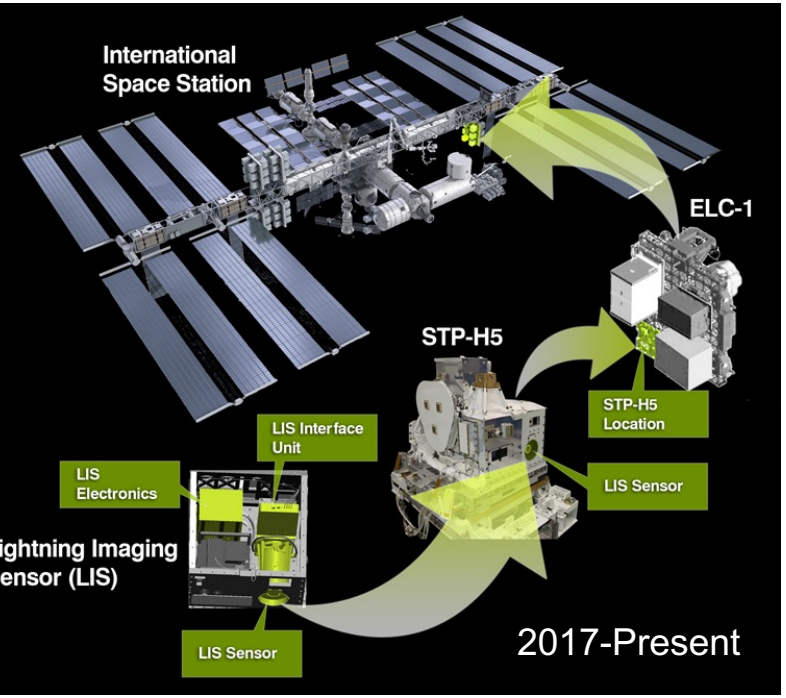
DATA
Jan. 1998 - April 2015

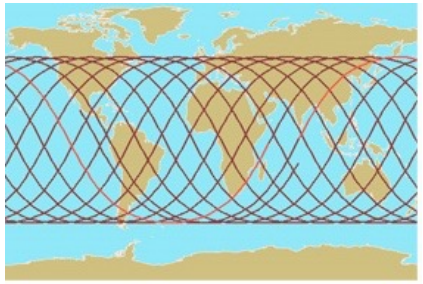


ORBIT
35° inclin., 350 km (boosted to 400 km in 2001) (detects to ~38°)

FIELD OF VIEW
600 x 600 km

DIURNAL CYCLE
sampled in 49 days



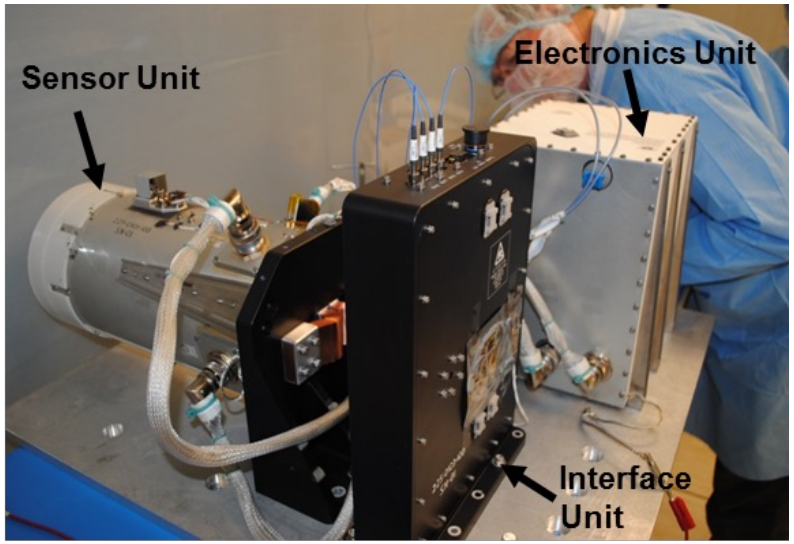


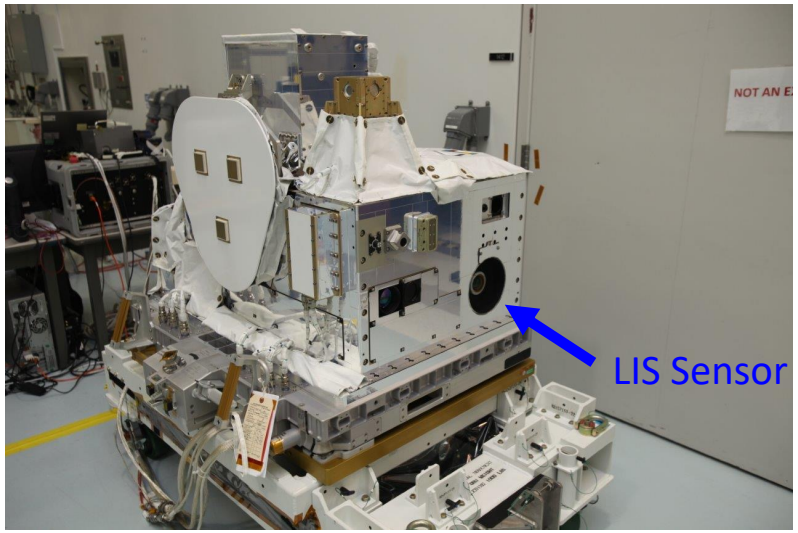
NASA Marshall has produced a 27-year (and counting) record of global lightning from space!

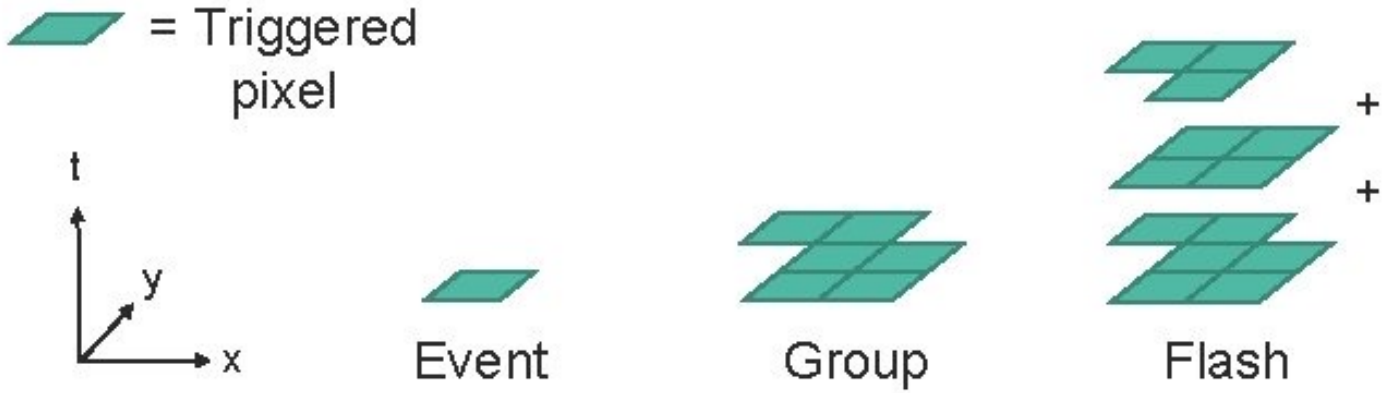
OTD → TRMM LIS → ISS LIS

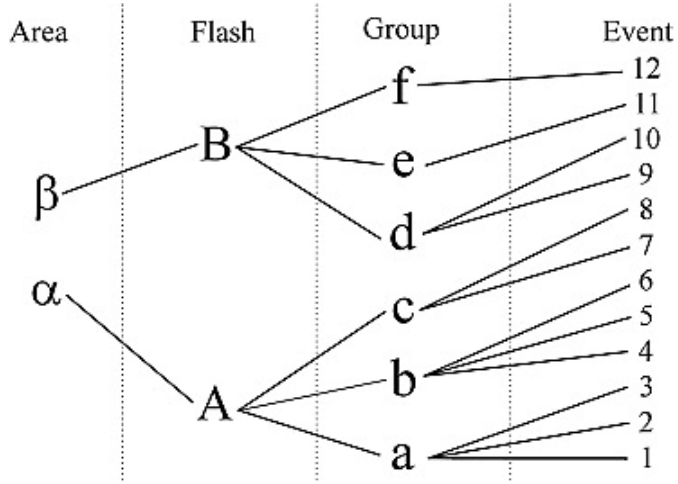
International Space Station Lightning Imaging Sensor (ISS LIS)

- ISS LIS is the flight spare of the original Tropical Rainfall Measuring Mission (TRMM) LIS, which was kept in storage since the 1990s.
- Modified and then integrated as a hosted payload on DoD Space Test Program-Houston 5 (STP-H5). Launched on SpaceX CRS-10 on February 19, 2017.
- LIS measures global lightning (amount, rate, radiant energy) during day and night, with storm-scale resolution, millisecond timing, and high, spatially uniform detection efficiency.





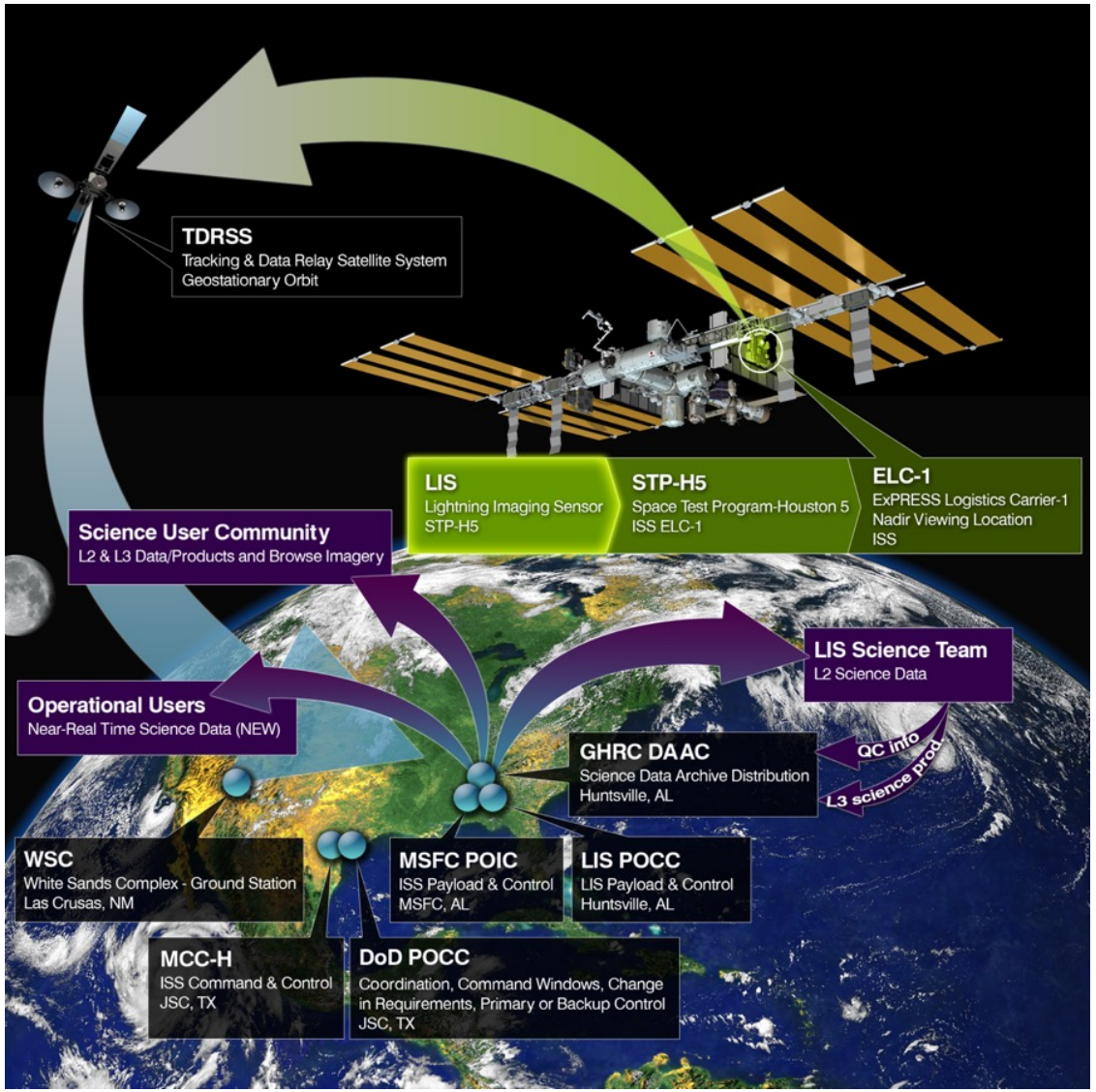




ISS LIS follows heritage data structure used by the Optical Transient Detector (OTD) and TRMM LIS

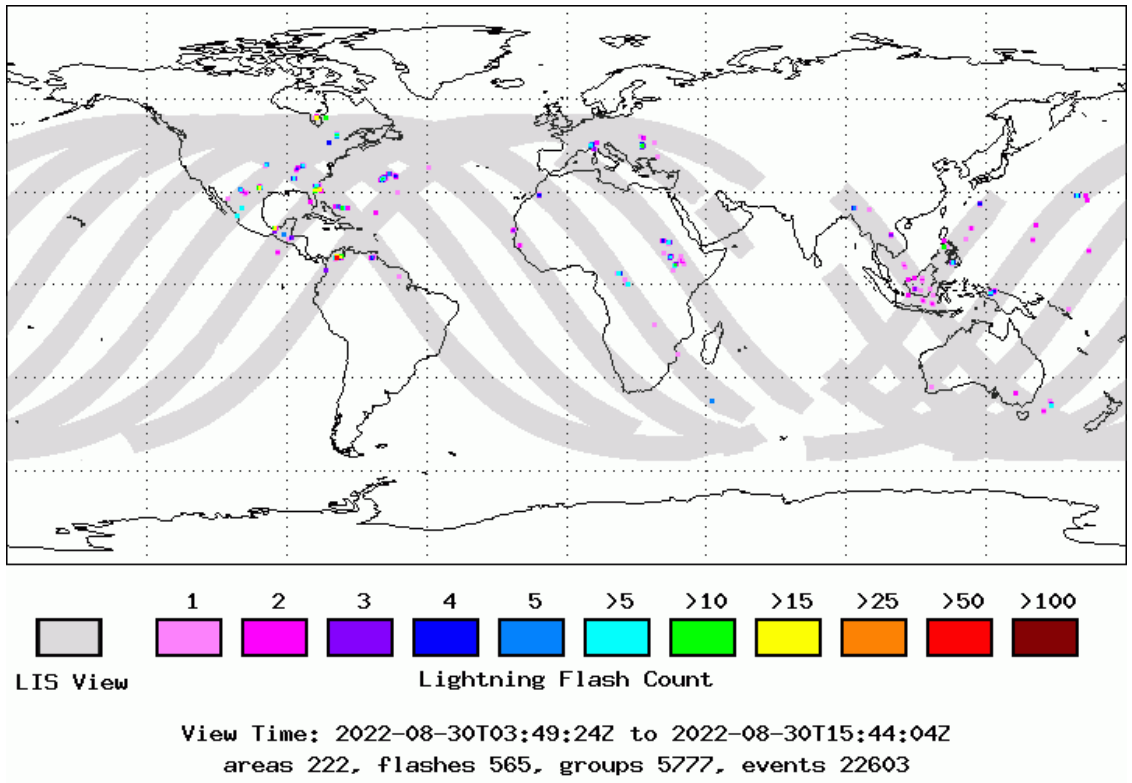
- Camera operates at 500 frames/sec, differences from running-mean image
- Views narrow band near 777 nm, which enables daytime detection
- 128 x 128 pixel focal plane

- Event = Single pixel in single frame
- Group = Multiple adjacent pixels in single frame
- Flash = Spatially/temporally clustered groups
- Area = Spatially/temporally clustered flashes (i.e., thunderstorm)

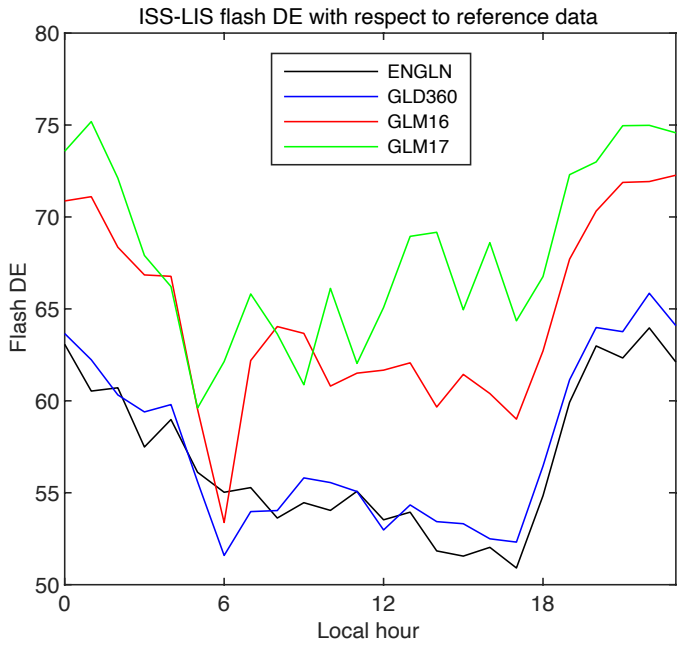


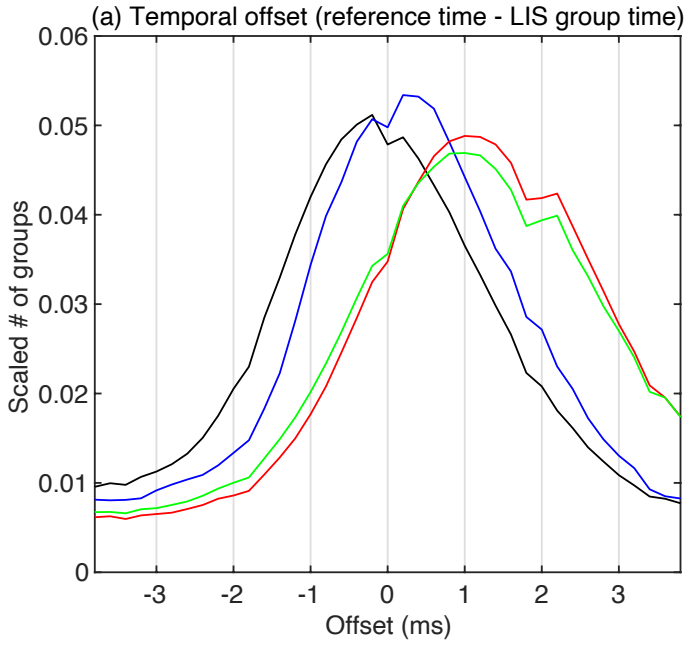
ISS LIS data are completely open and available in near-realtime from the Global Hydrometeorology Resource Center (GHRC)

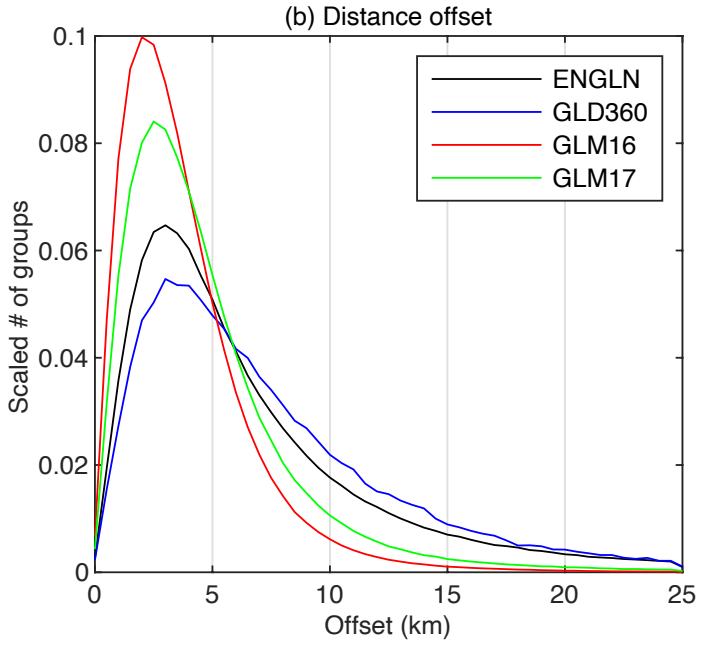
https://ghrc.nsstc.nasa.gov/lightning/data/data_lis_iss.html



ISS LIS Performance





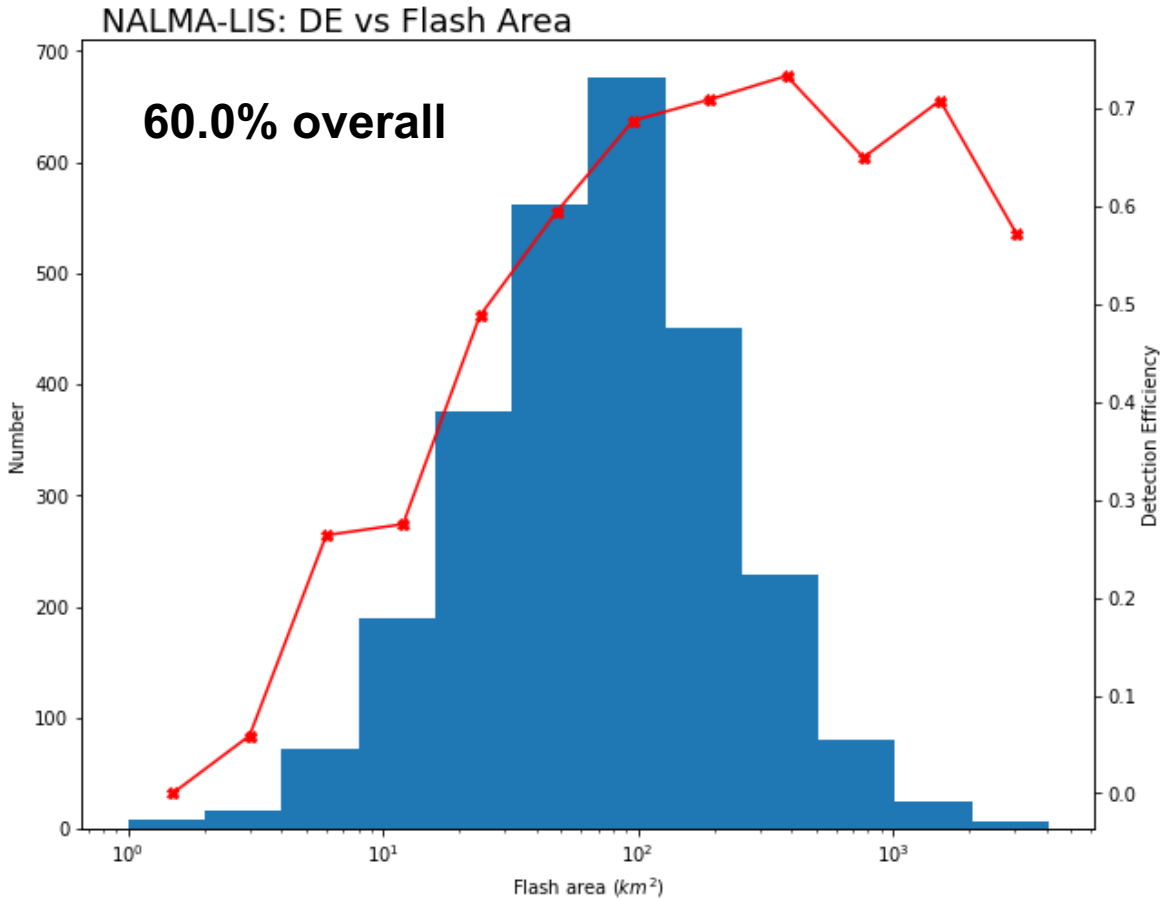


Detection Efficiency ~60%
(Relative to reference datasets)

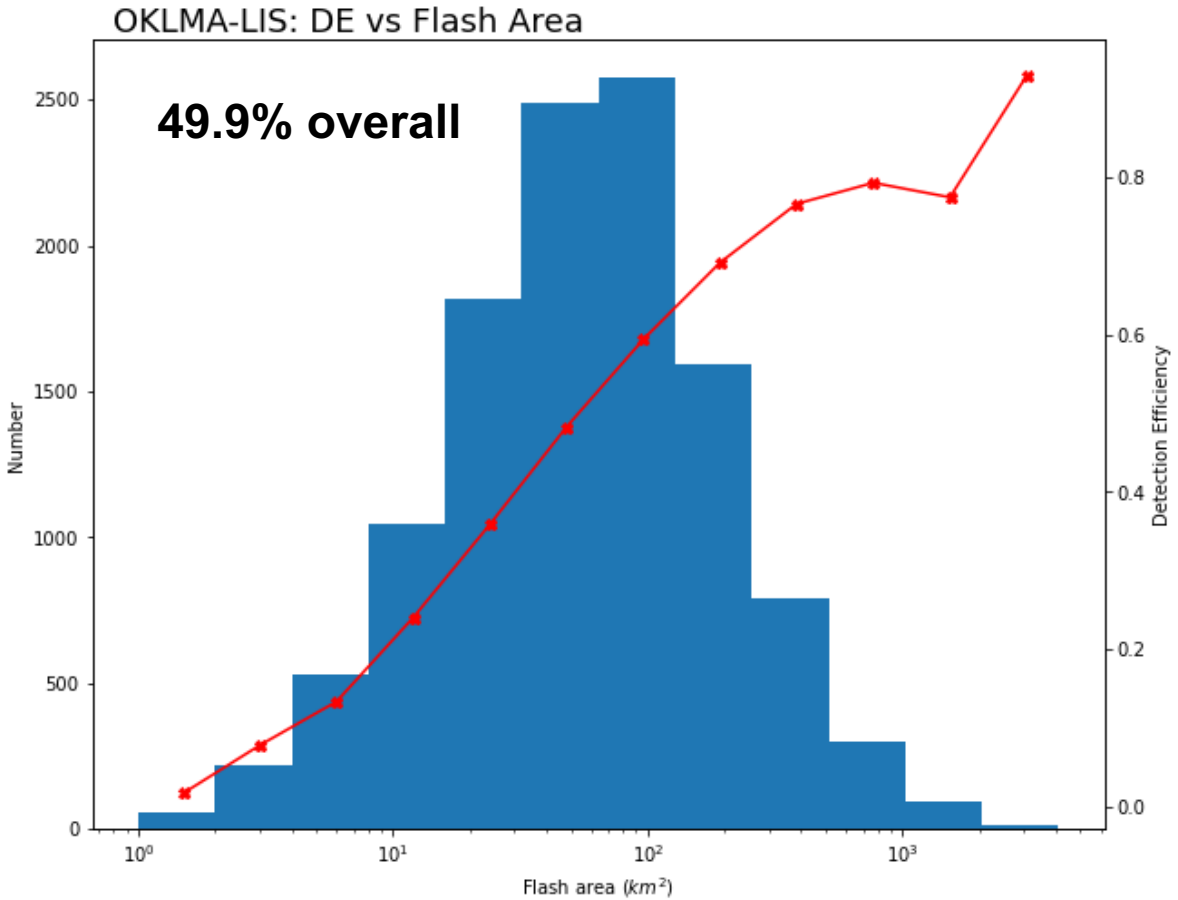
Timing Accuracy +/- 1 ms
(Sub-Frame)

Location Accuracy < 5 km
(Sub-Pixel)

North Alabama LMA

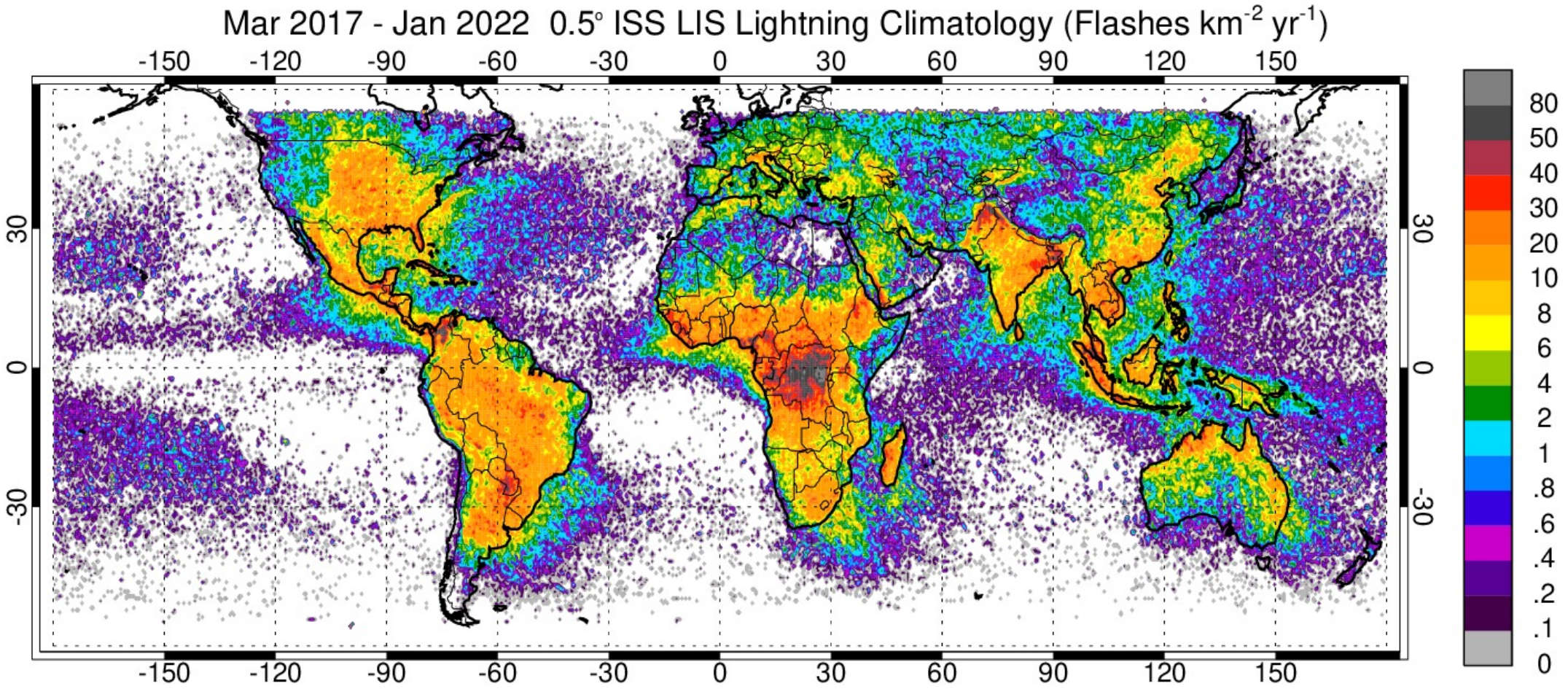


Oklahoma LMA



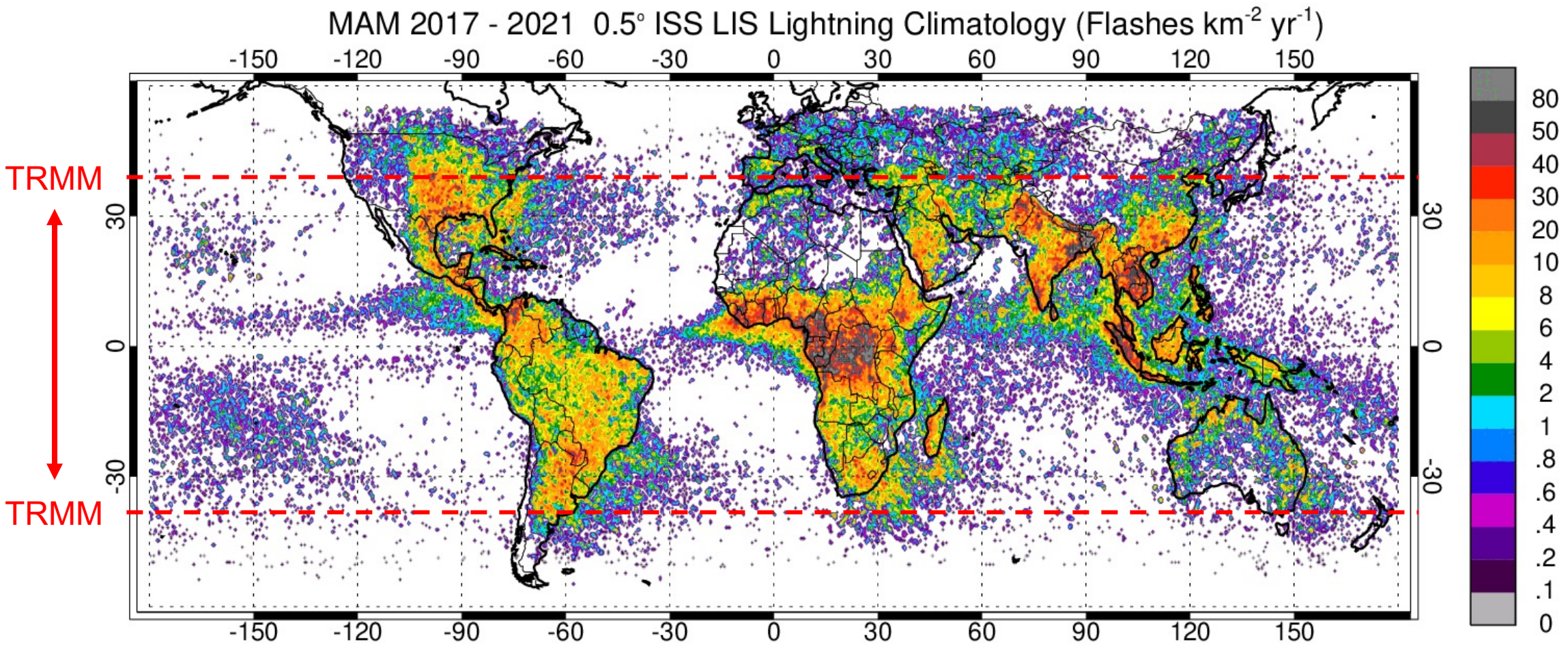
Influence of anomalously electrified storms in Central Plains?

5-Year Climatology

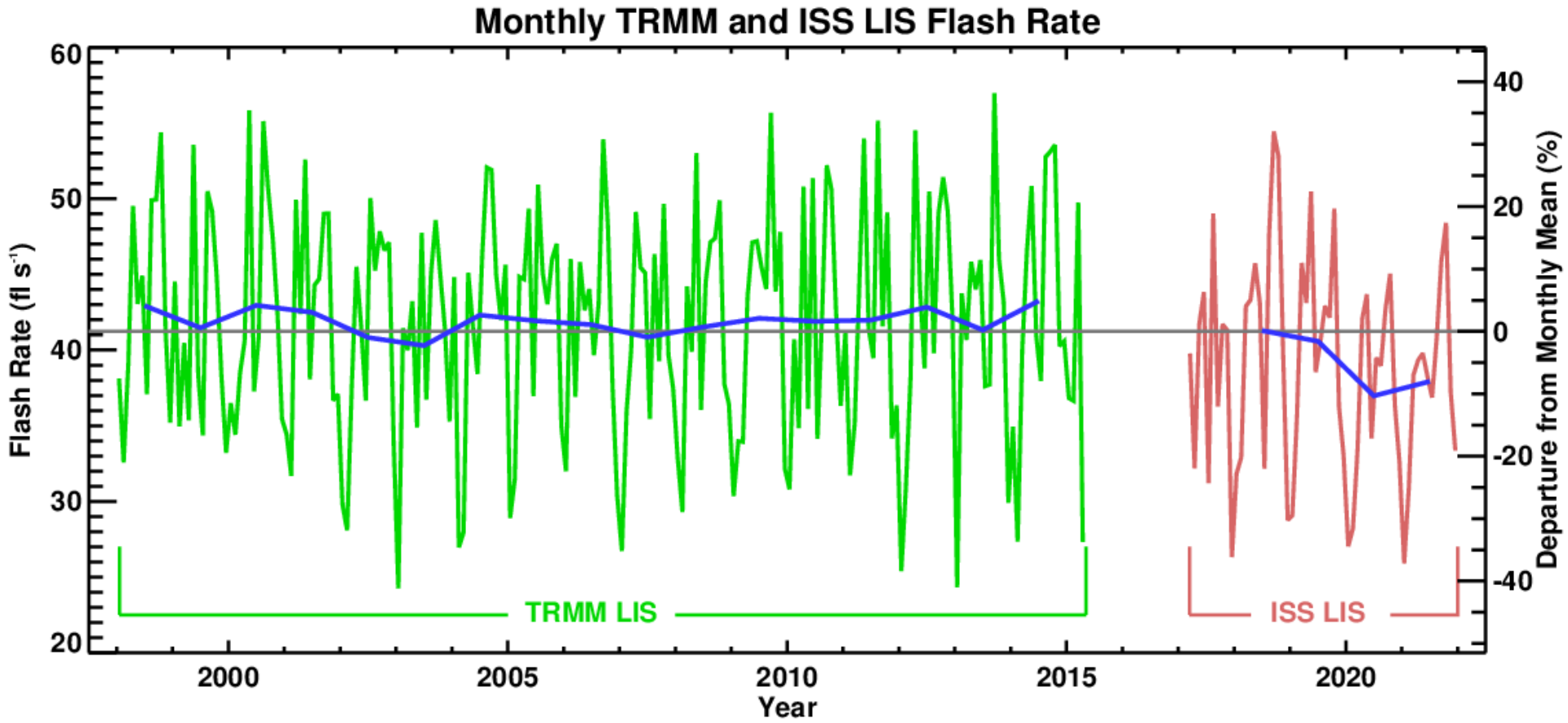


98% of global lightning is in view of ISS LIS!

Seasonal Variability

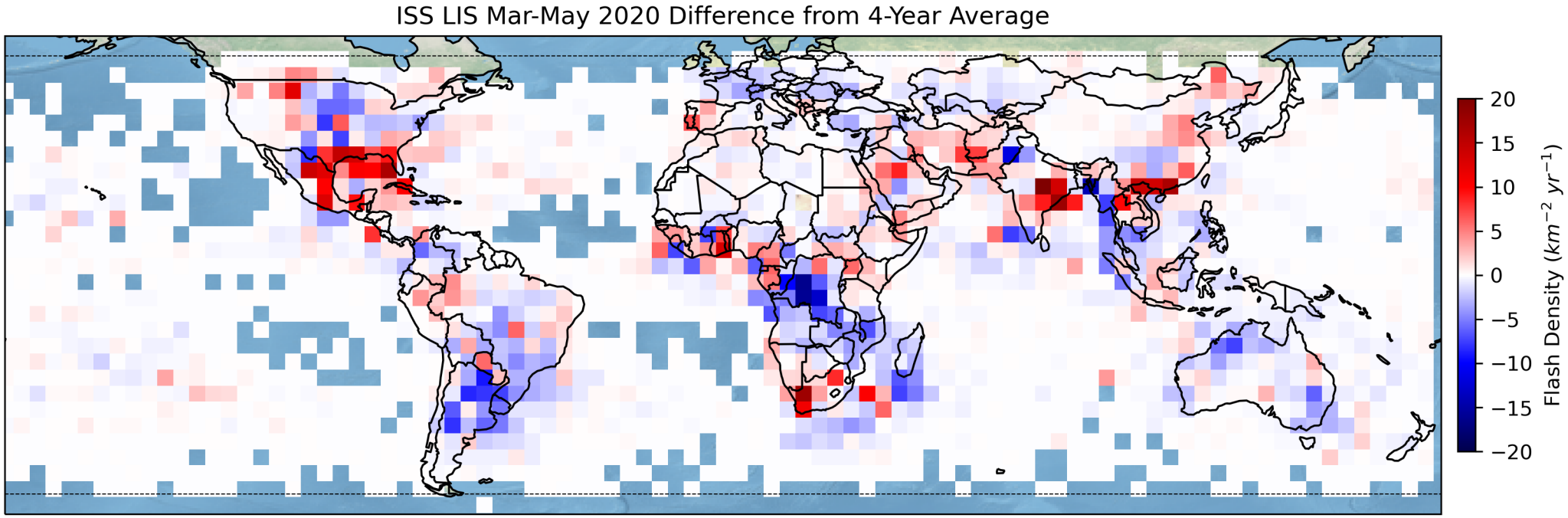


Global Lightning Trends

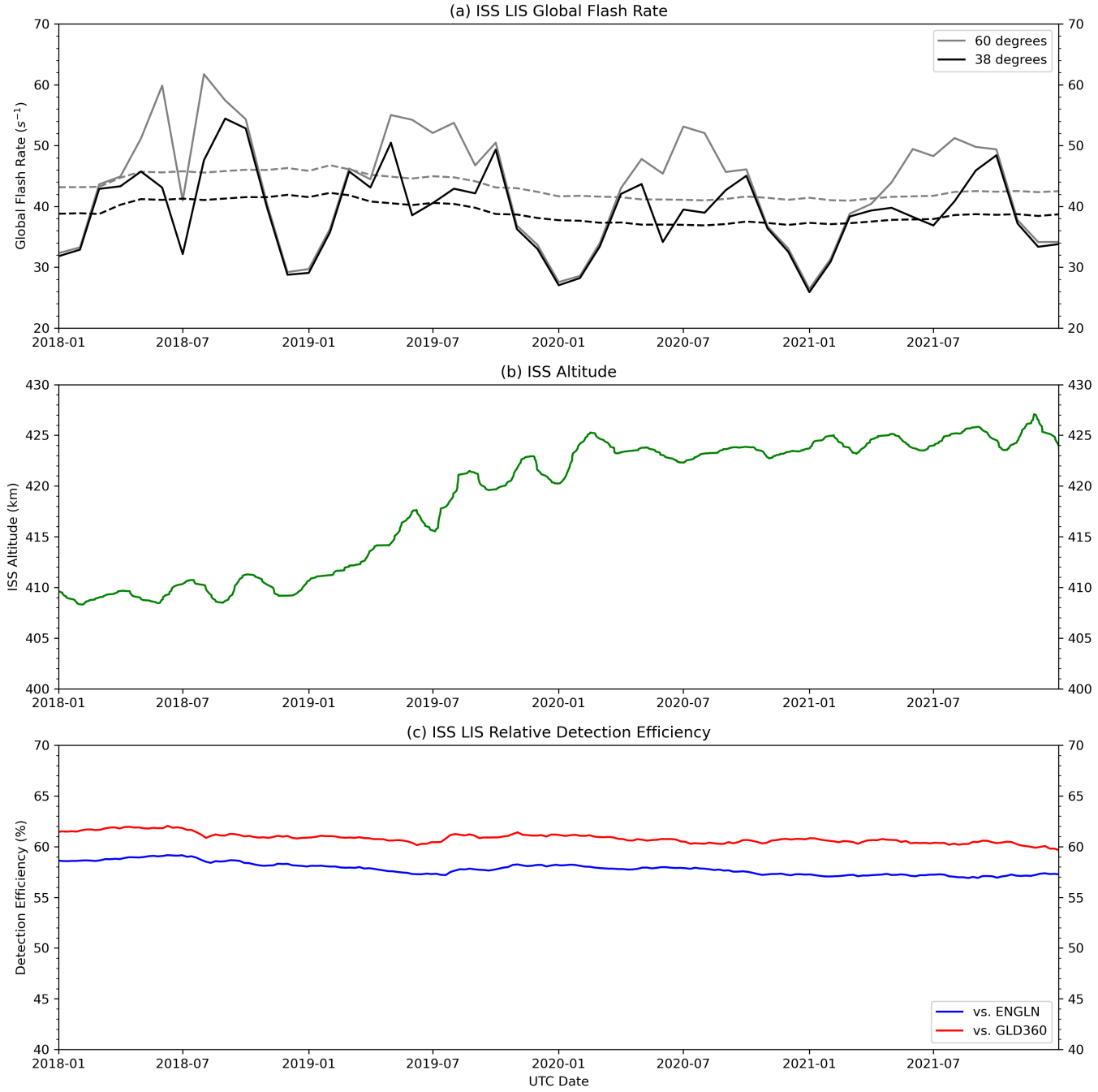


(Only lightning within +/-38 degrees latitude shown)

Lightning Reduction During COVID?

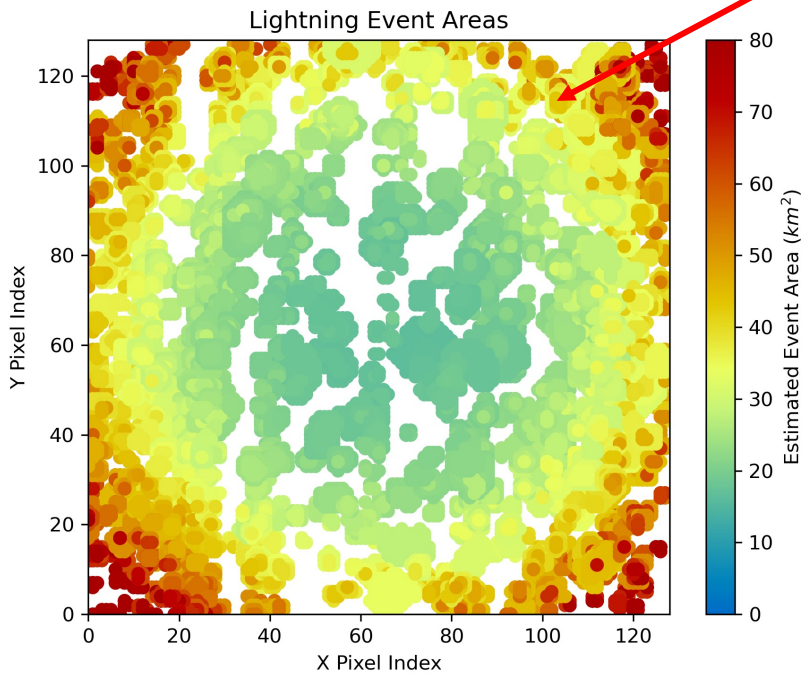


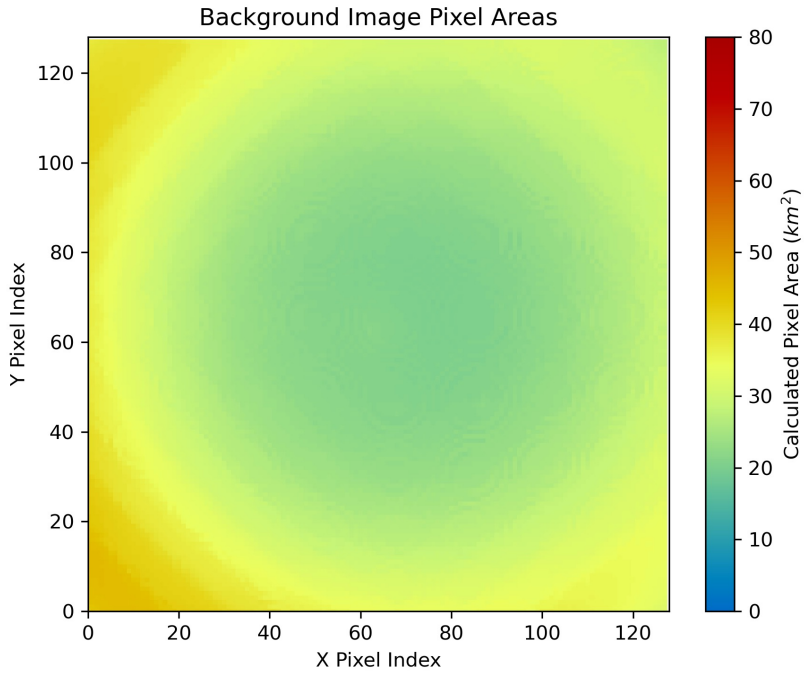
- Lightning was globally reduced during the major COVID lockdown period (spring 2020), but with significant regional heterogeneity
- Global lightning remained lower into 2021

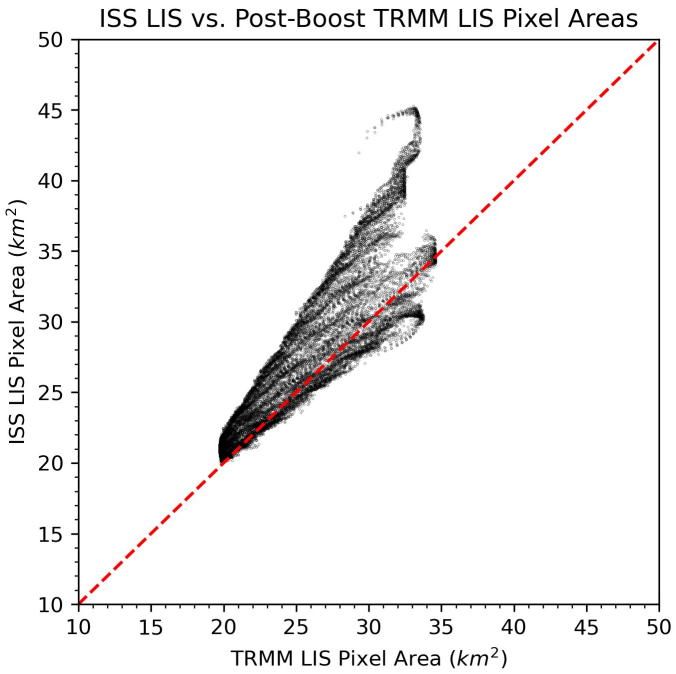


- Lightning down 3.0% between ±60° in 2020 (vs. 2018-2019)
- Lightning down 10.6% in same period between ±38°!
- ISS altitude increased ~15 km during this time, but detection efficiency only declined 0.3-0.4%

We will fix this!

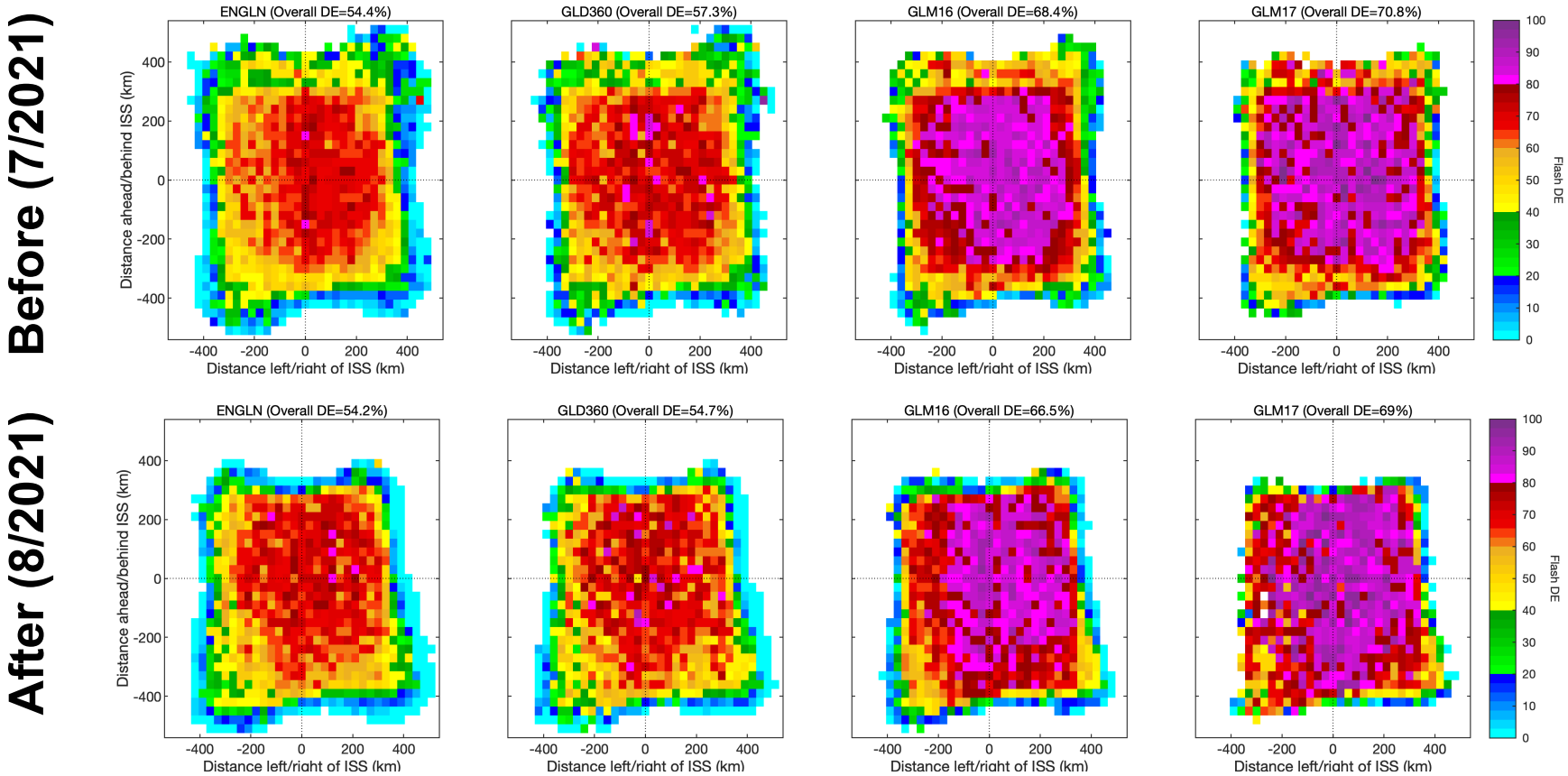


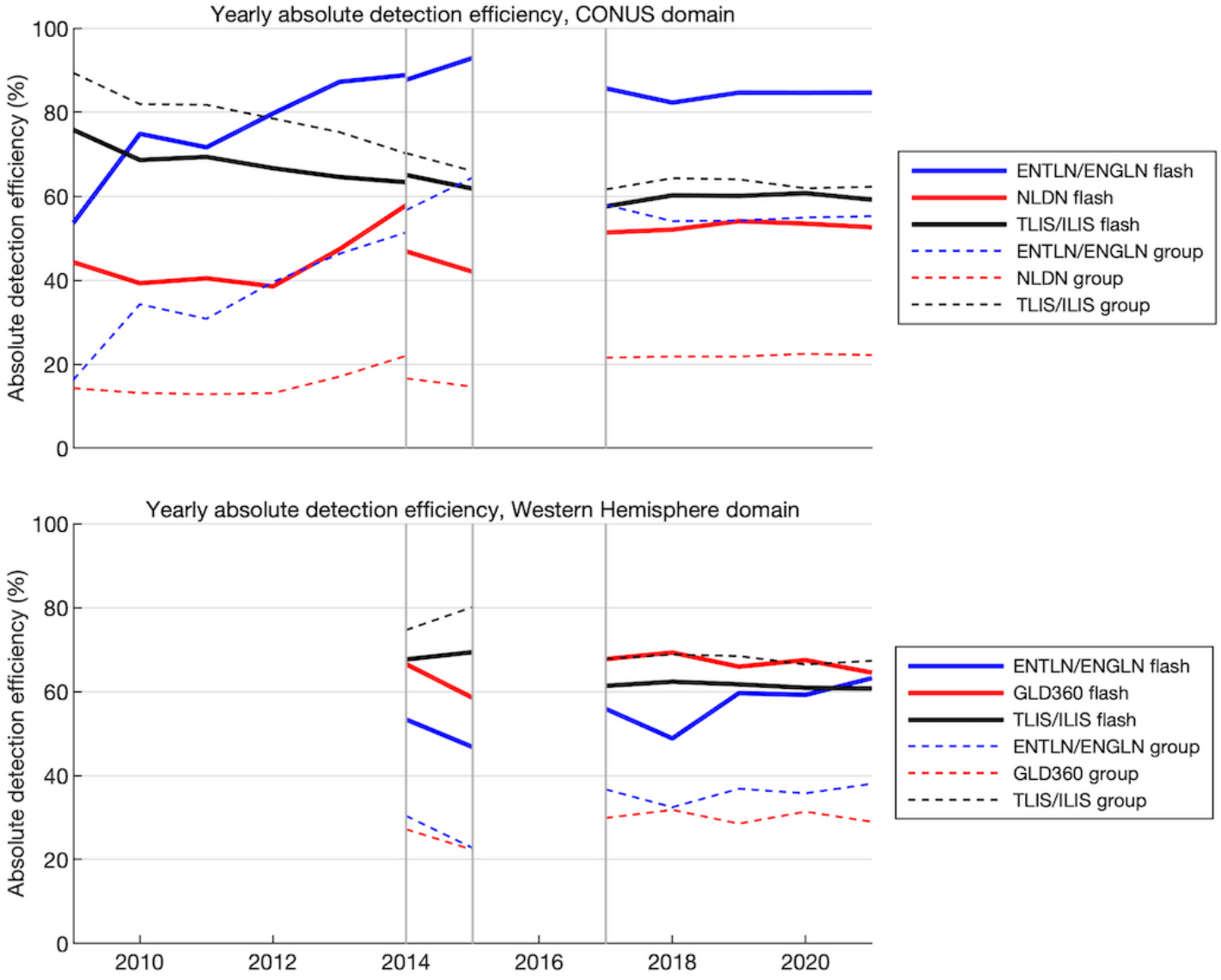




- LIS event area estimates are biased high off-boresight
- Corrected LIS pixel areas show ISS consistently larger than post-boost TRMM
- This is not just altitude, ISS attitude skewed from nadir

- The Russian ISS module added in 2021 changed the pitch of the ISS, which modestly degrades LIS detection efficiency (~1-2%) due to camera angle change
- Below we show before & after DE in instrument field of view vs. 4 different reference datasets
- Need to treat this and another expected future pitch change as separate epochs in analyses.



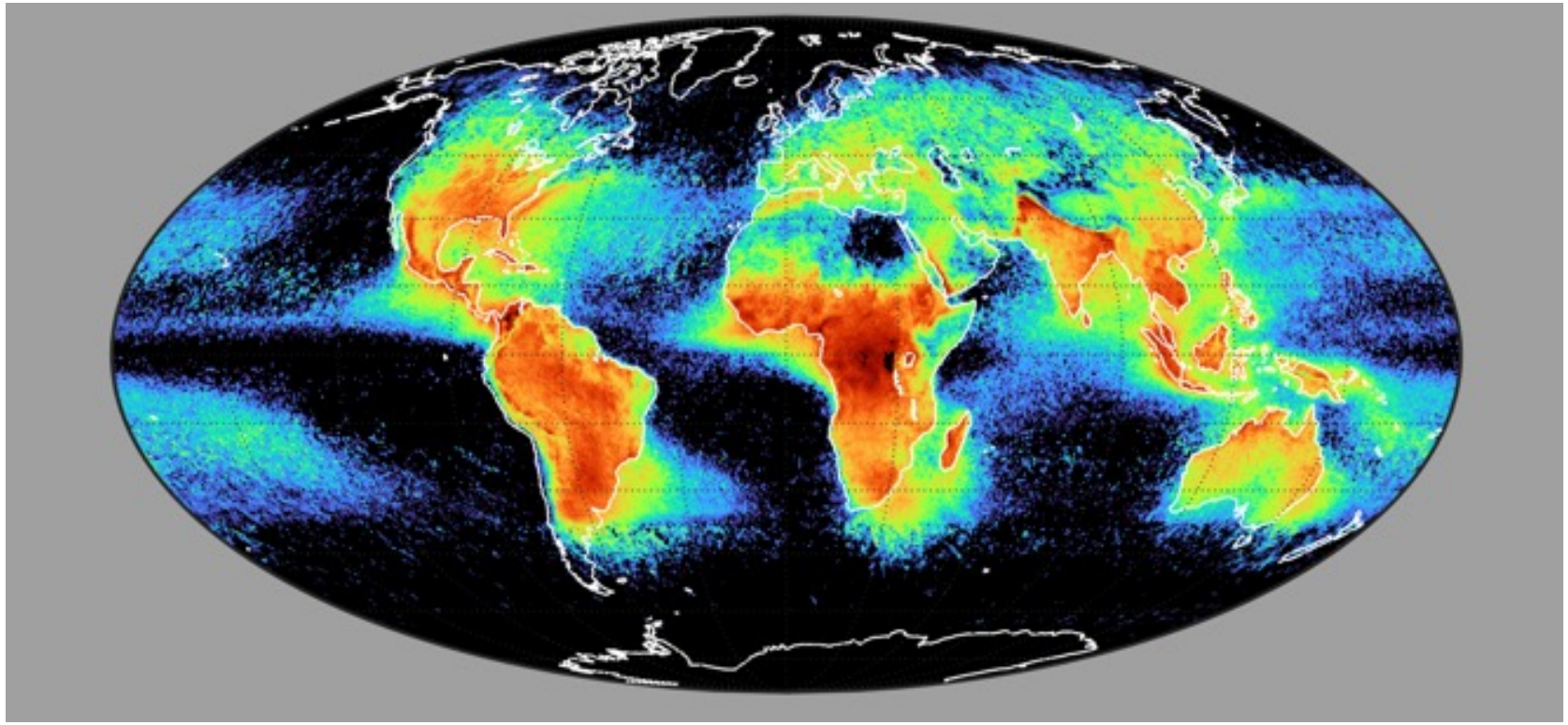


- Absolute detection efficiency of ISS LIS compared to TRMM LIS and multiple reference datasets
- TRMM years show effects of improving ground networks
- ISS detection efficiency is stable, but ~5% lower than TRMM LIS (which was likely significantly lower than originally advertised)

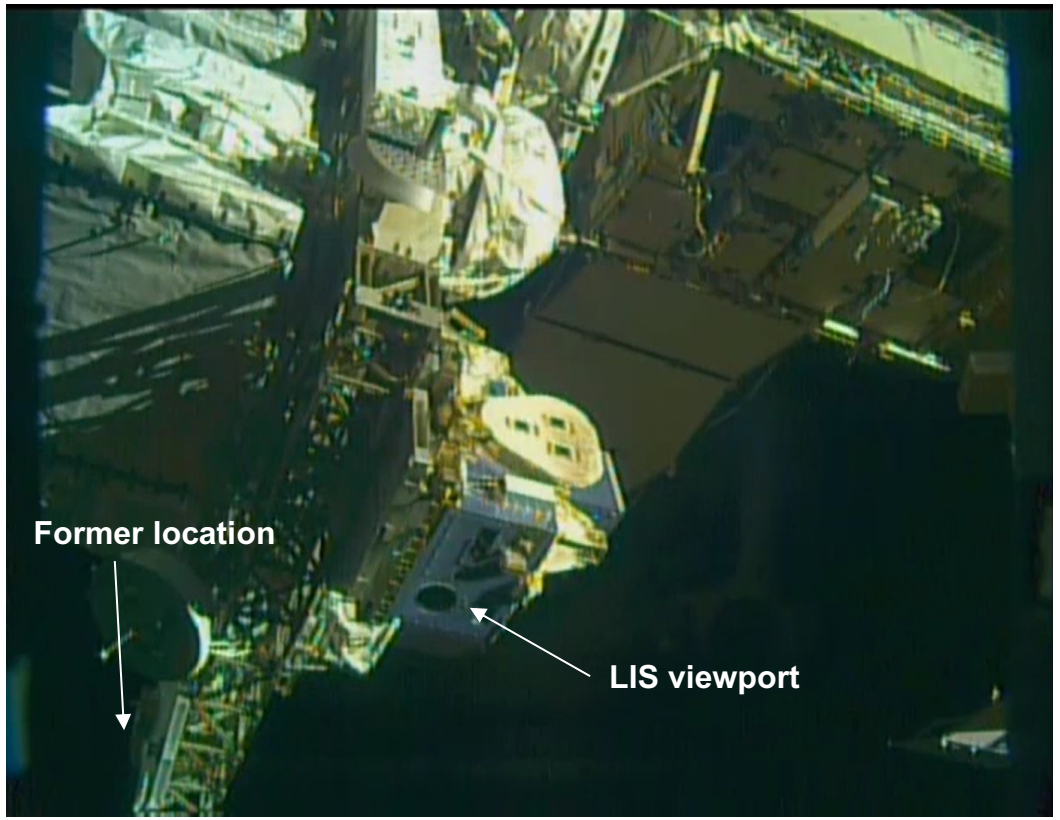
Integrating the Long-Term Global Lightning Record

- Building a more accurate 25+ year record of global lightning (i.e., OTD + TRMM/ISS LIS) requires accurate intercalibration, in order to fully account for instrument and mission differences

- Ties in with lightning declared as an Essential Climate Variable (ECV) by the WMO



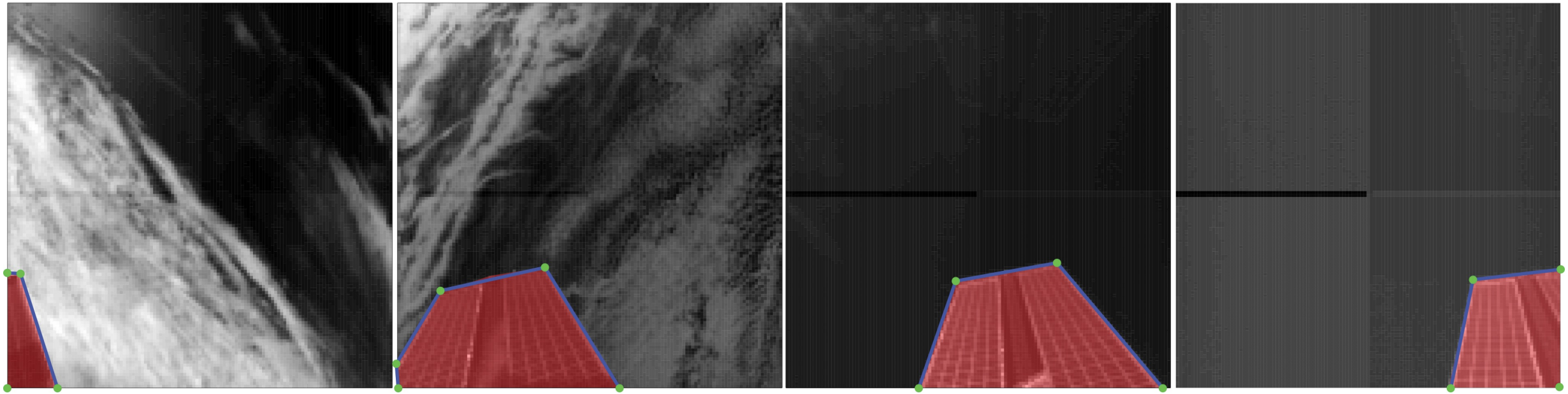
ISS LIS Relocation – 7 July 2022



- STP-H5/LIS being carried by robotic arm during relocation
- STP-H5/LIS in new site on ELC-1 (site 3)

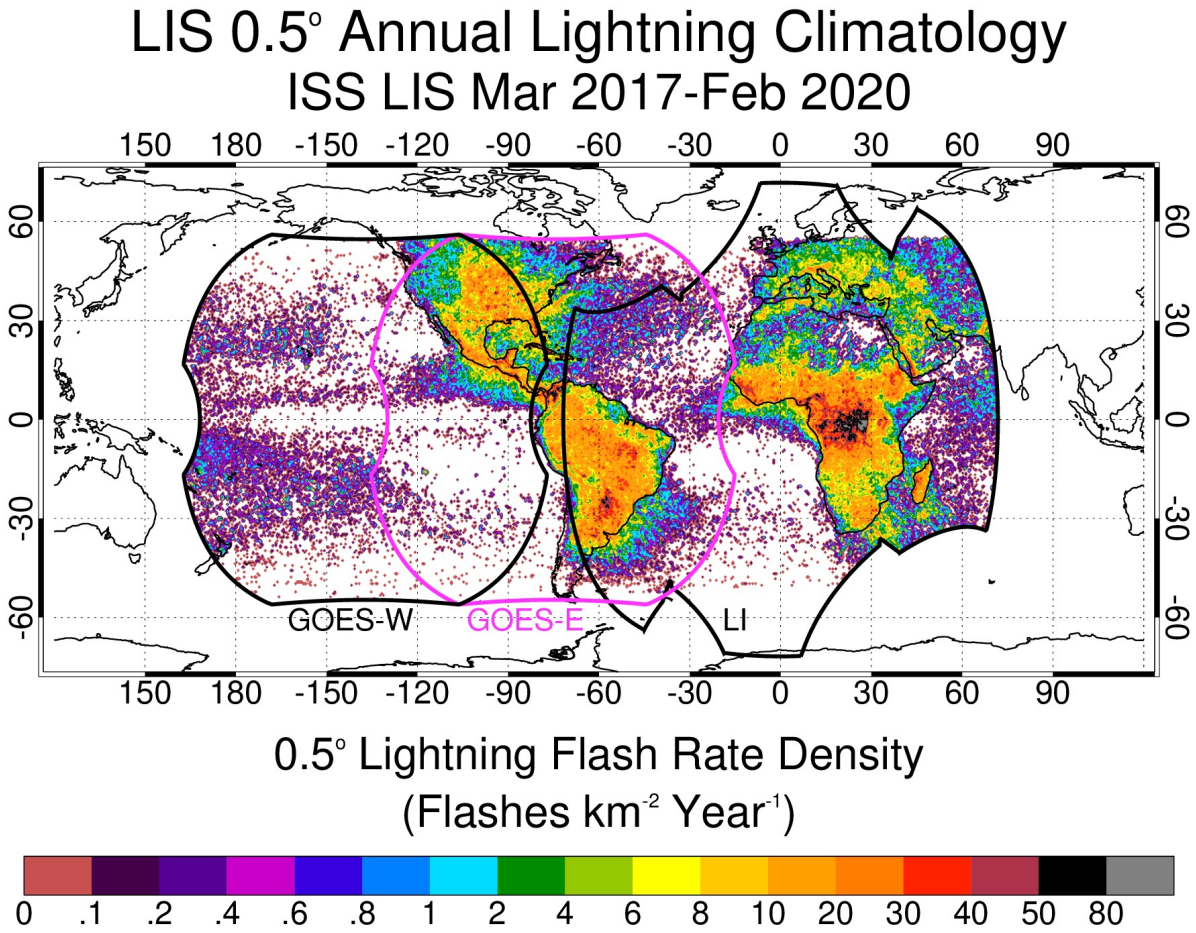
- The relocation of STP-H5/LIS enables at least 1.5 years additional time on the ISS (thru December 2023 at earliest)

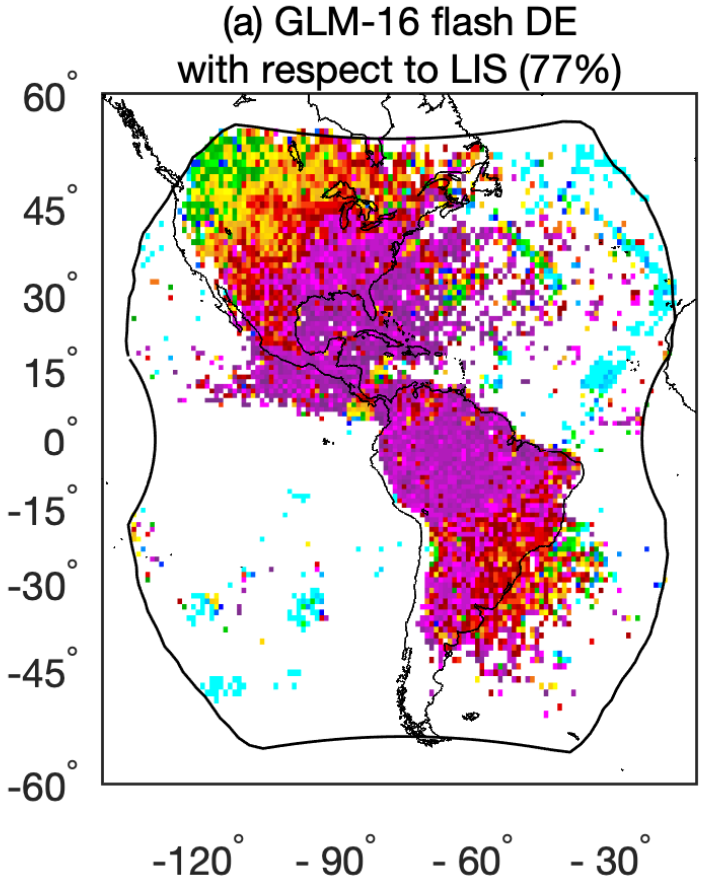
- Corrected (but not yet quality-controlled) post-relocation data are now available as version 2.2 on GHRC! (v2.1 QC data available thru June 2022)



ISS LIS SCIENCE APPLICATIONS

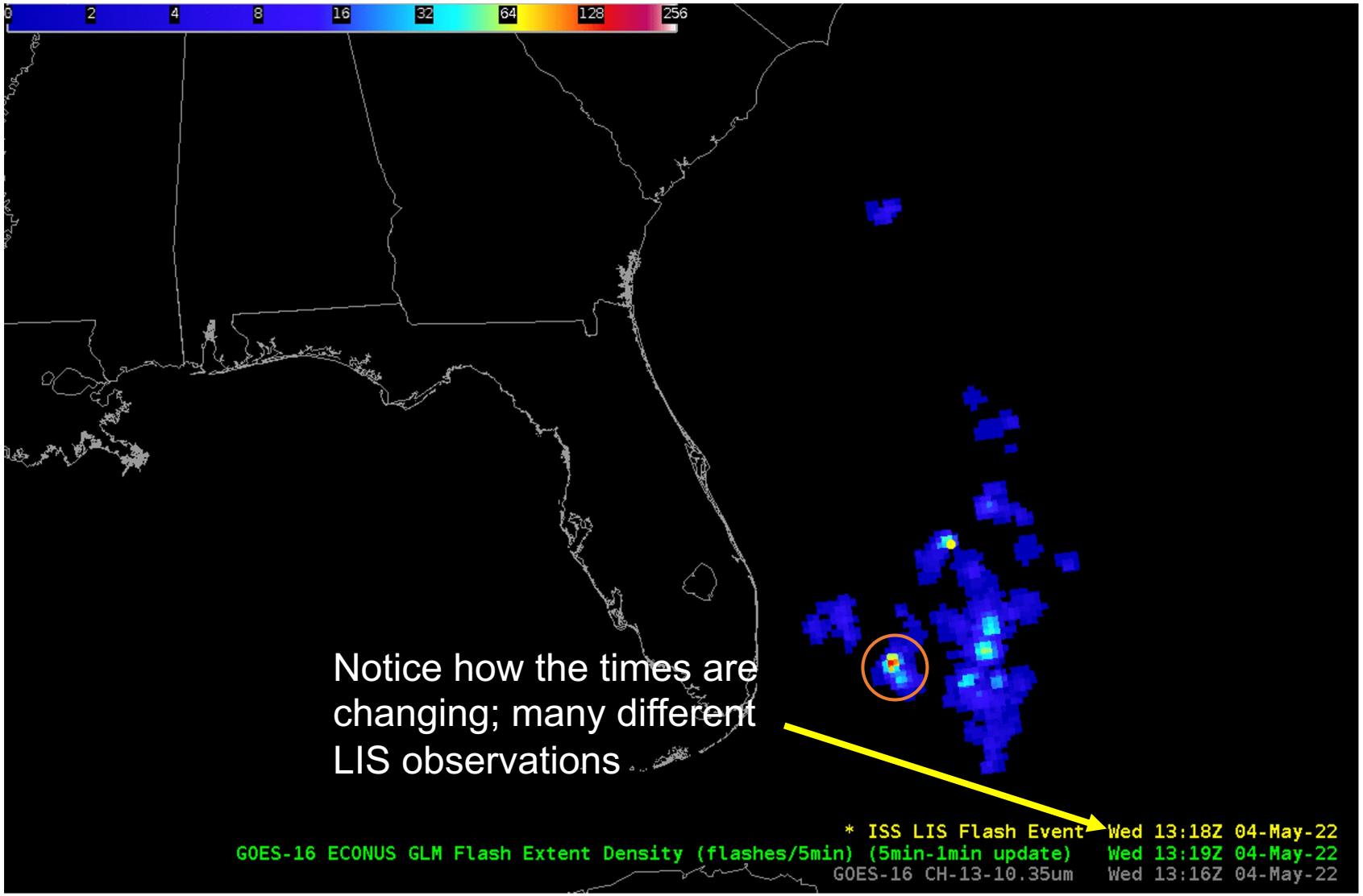
Validation of Geostationary Lightning Observations

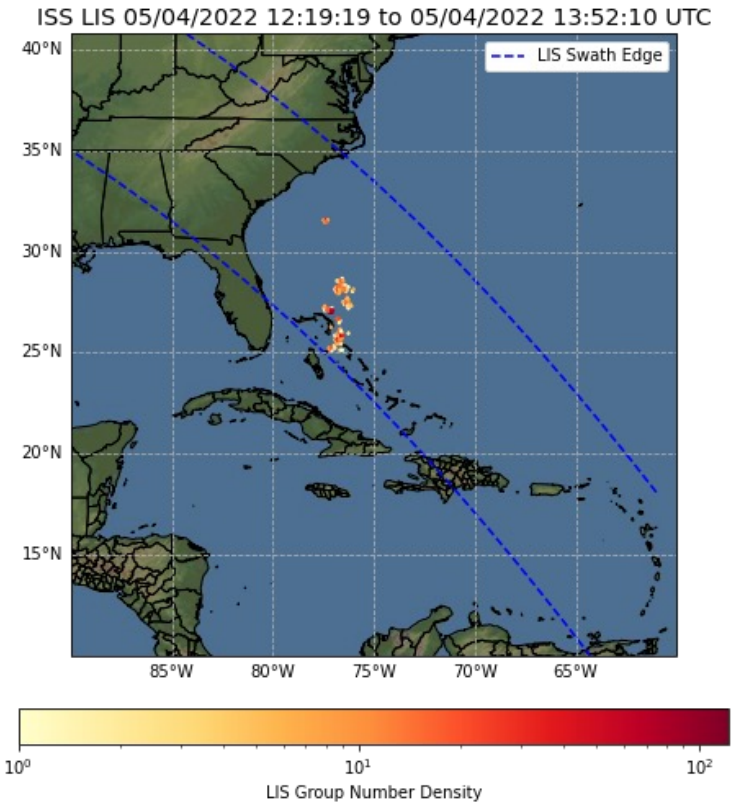




- GLMs have reduced sensitivity near the edges of their FOVs
- ISS LIS has a more nadir view during overpasses, enabling it to detect additional lightning

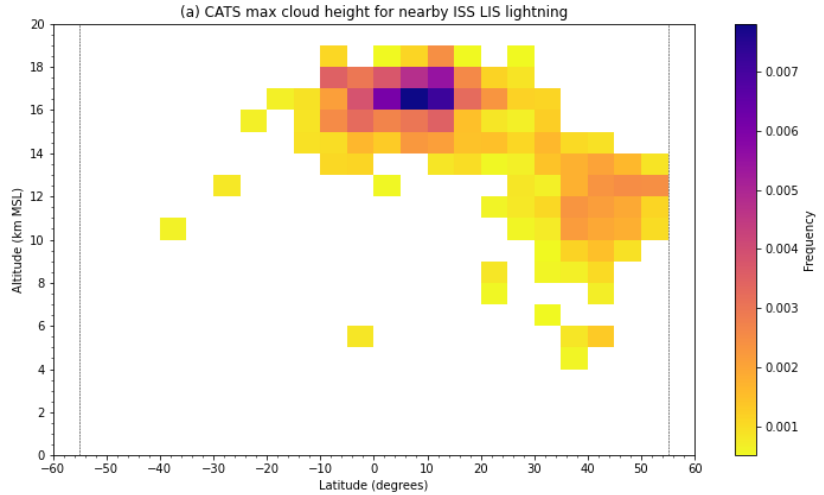
ISS LIS in Operational Forecast Tools



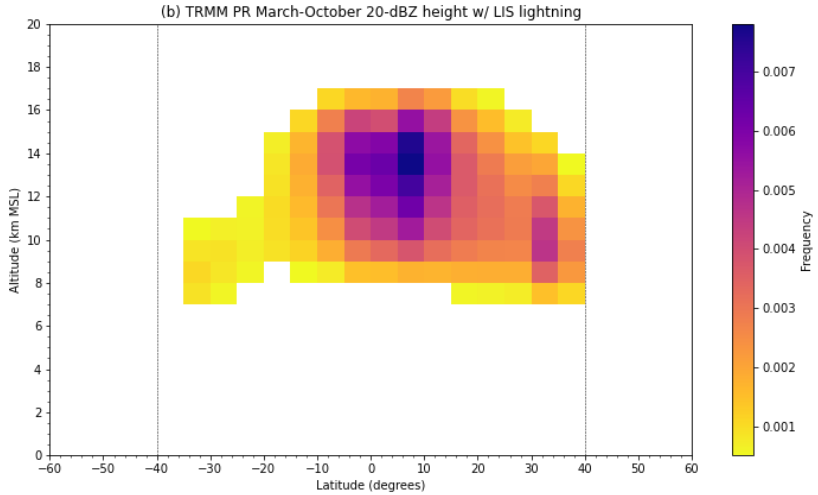


- Additional work can be done (e.g., FED, swath edges, etc.)

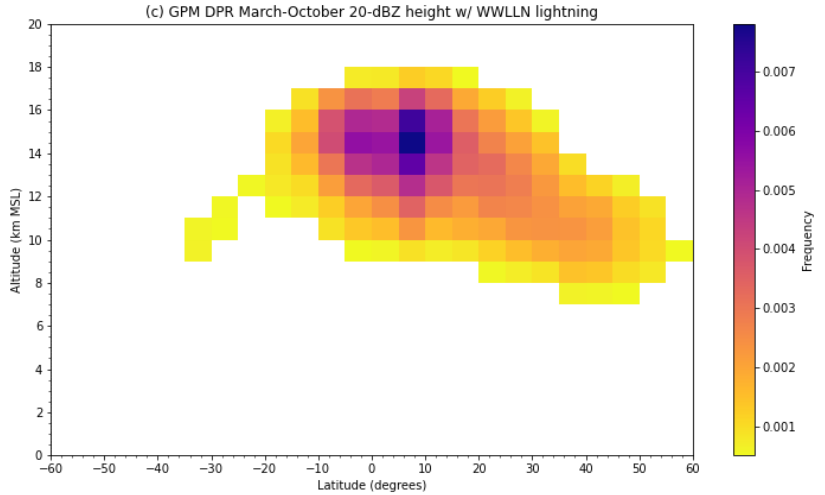
CATS + ISS LIS



TRMM



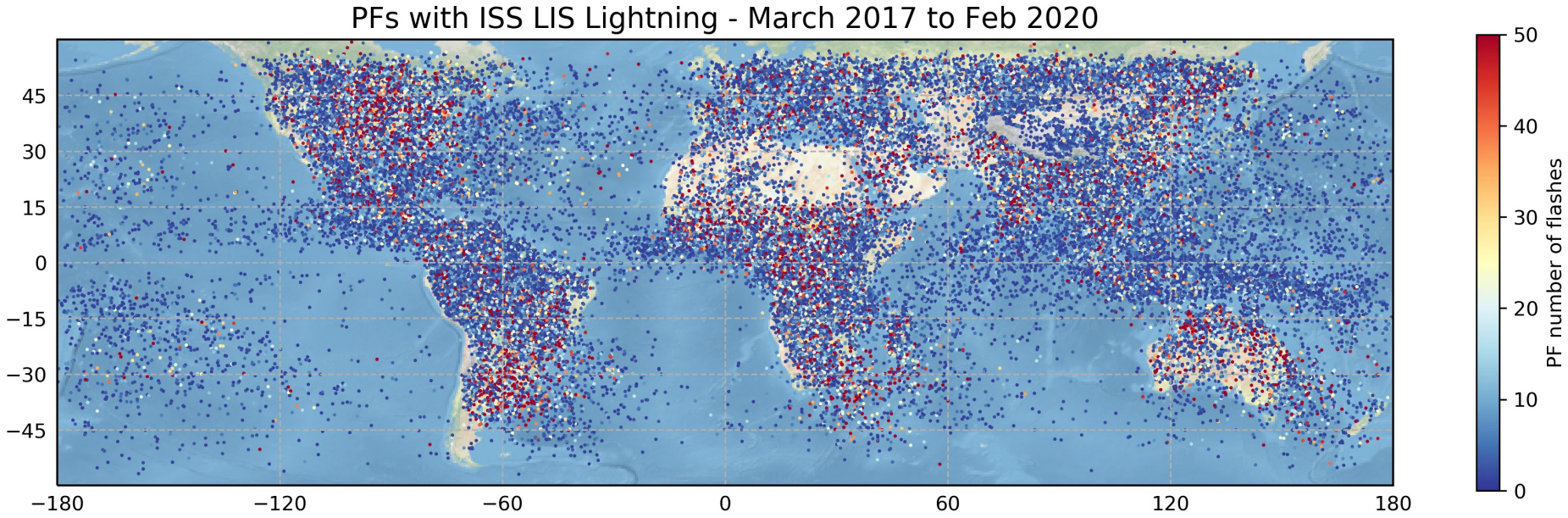
GPM + WWLLN



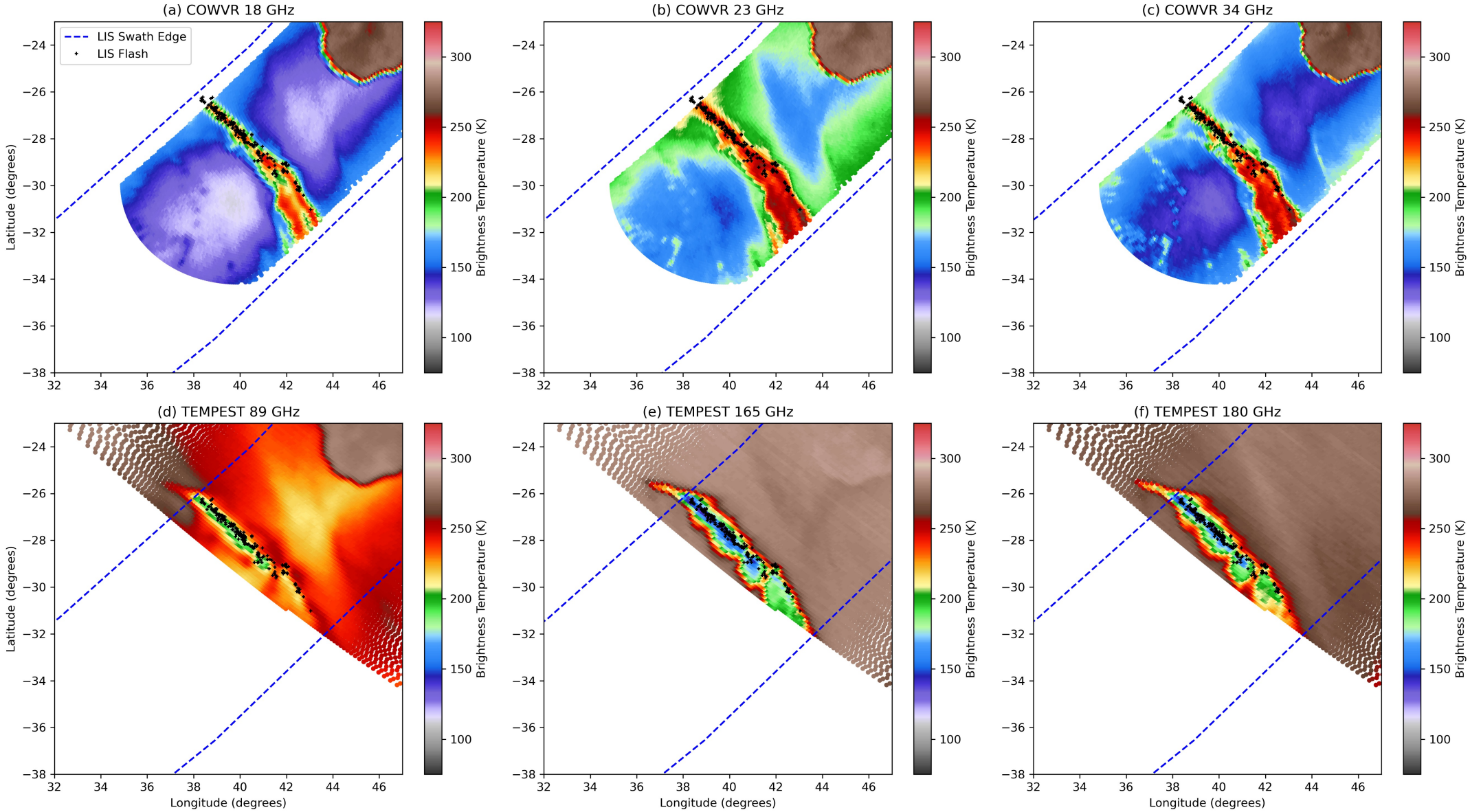
- ISS LIS observations combined with the Cloud-Aerosol Transport System (CATS) measurements of cloud-top height during their March-October 2017 overlap period
- Compared to similar months in TRMM, Global Precipitation Measurement (GPM), and the Worldwide Lightning Location Network (WWLLN) datasets.
- Results demonstrate the viability of combining global lidar and lightning observations for documenting thunderstorm structure.

Lightning and Microwave Radiometer Precipitation Features

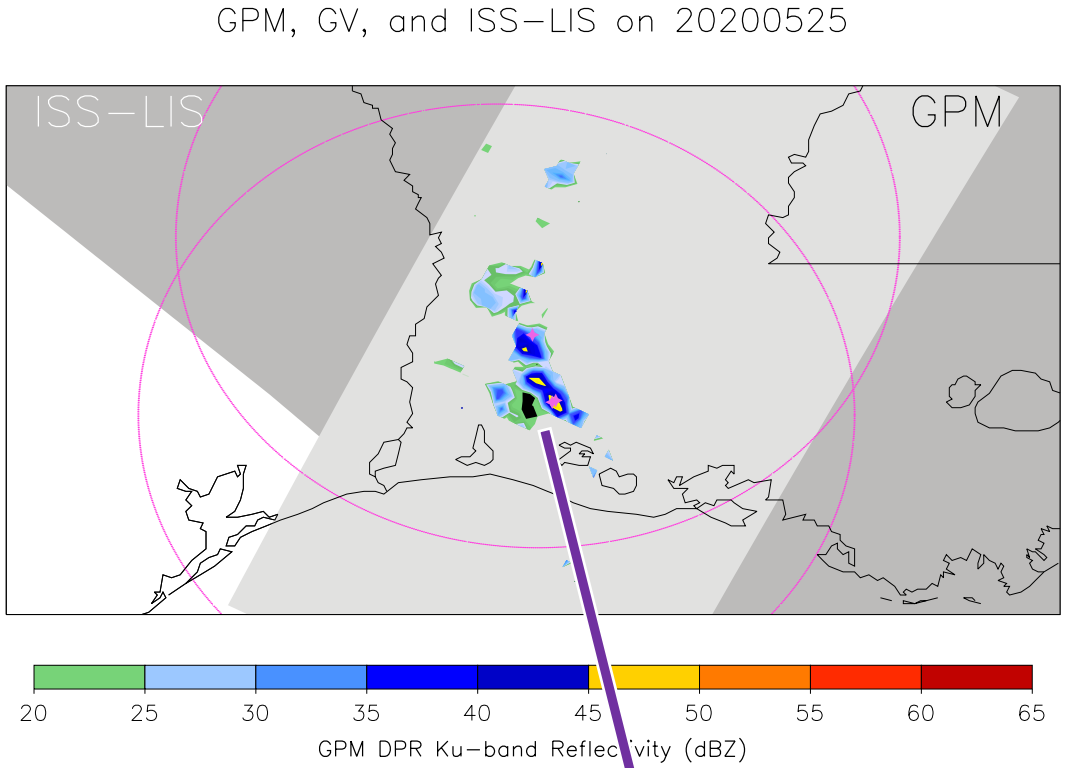
- Thru Feb 2020: 55,761 GPM PFs containing lightning (~18.5k / yr), ~23% poleward of +/-38°
- 913,860 total ISS LIS flashes in these PFs
- Within ~40% of TRMM annual rate of PFs w/ lightning (Cecil et al. 2005); 9 radiometers contributing
- STP-H8/ASAP multi-frequency radiometers on ISS support coincident matchups!



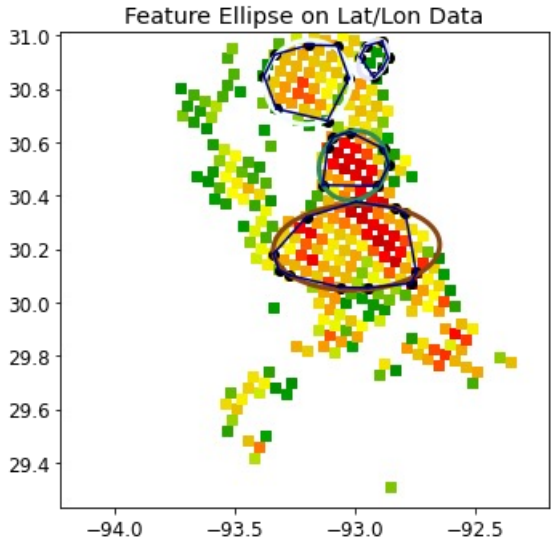
STP-H8's COWVR/TEMPEST + ISS Lightning Imaging Sensor

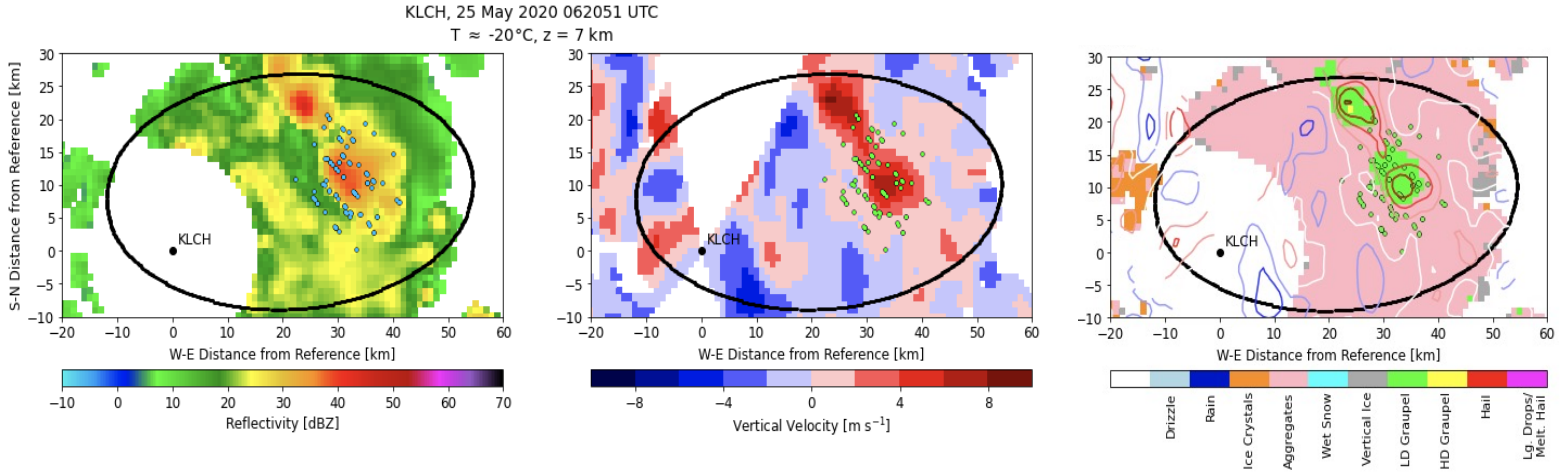


Lightning and Ground Observations

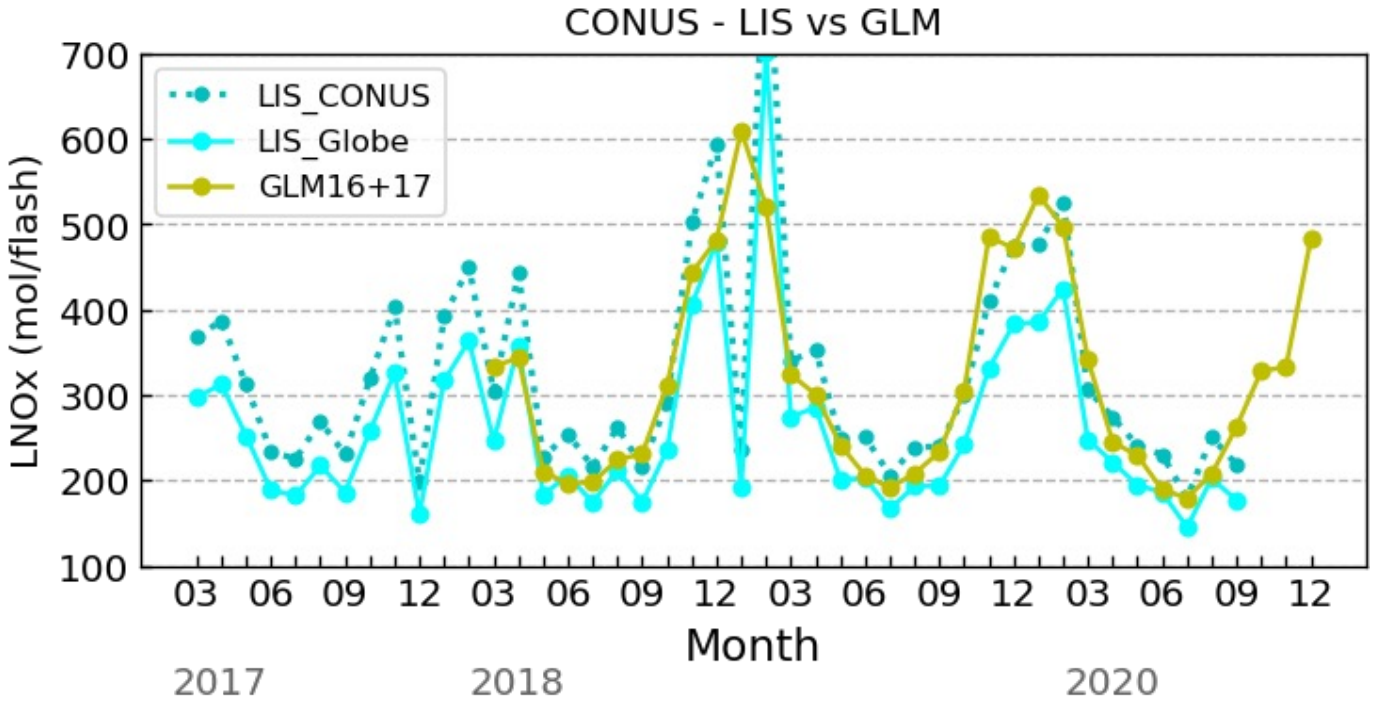


- ISS LIS data are being combined with ground-based observations from the Global Precipitation Measurement (GPM) Validation Network, including polarimetric, multi-Doppler radar networks
- Enables development of future lightning-based retrievals of thunderstorm properties





Lightning-Produced Nitrogen Oxides



Estimated LNOx per-flash production for CONUS

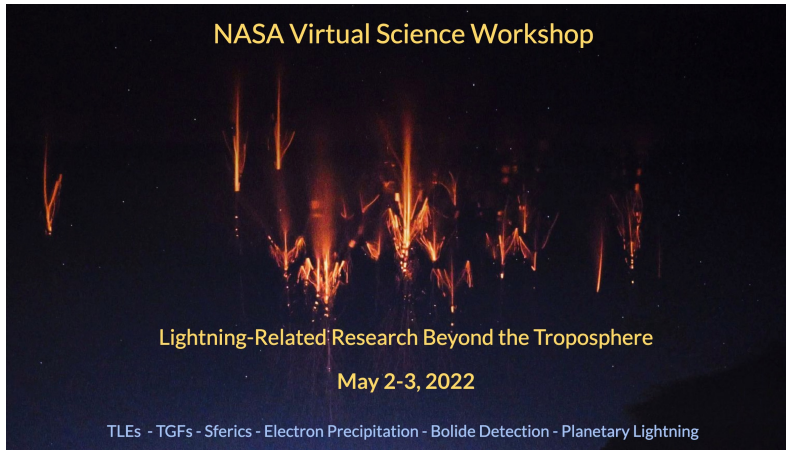
LIS_CONUS and LIS_Globe used β derived from different subsets of ISS LIS data

LNOx model (β-method; Koshak, 2017) for satellite lightning observation

- Relates LNOx (P) with detected flash optical energy (Q)

$$P = N\overline{P} = \frac{Y}{\beta\, N_A} \sum_{k=1}^{N} Q_k$$

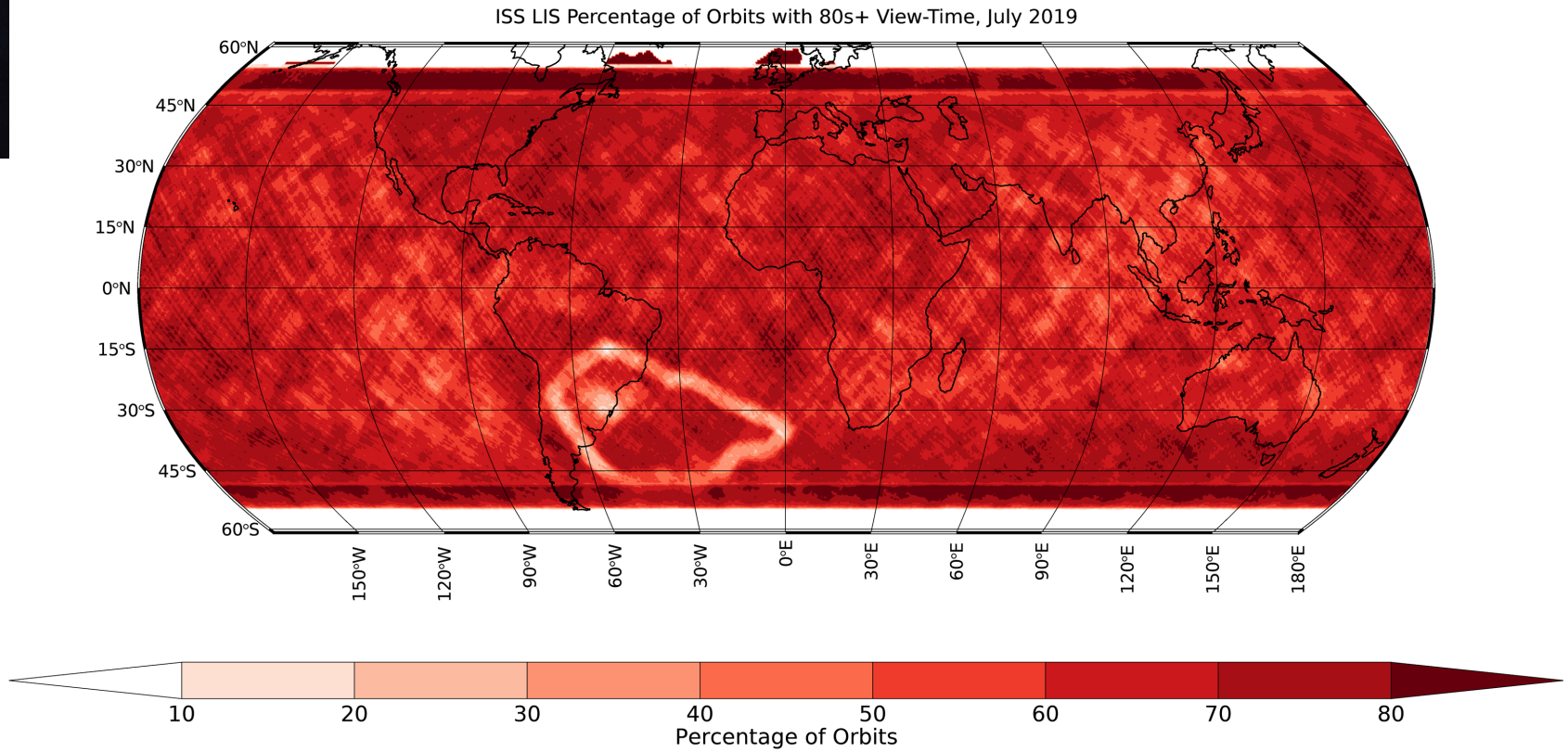
- Applicable for regional/cross-continental domain (with GLM et al.) for air quality and climate studies
- Consistency across satellite datasets
  - enables the use of ISS LIS for cross-calibration with future satellite observations
  - supports previous global estimates based on ISS LIS observations



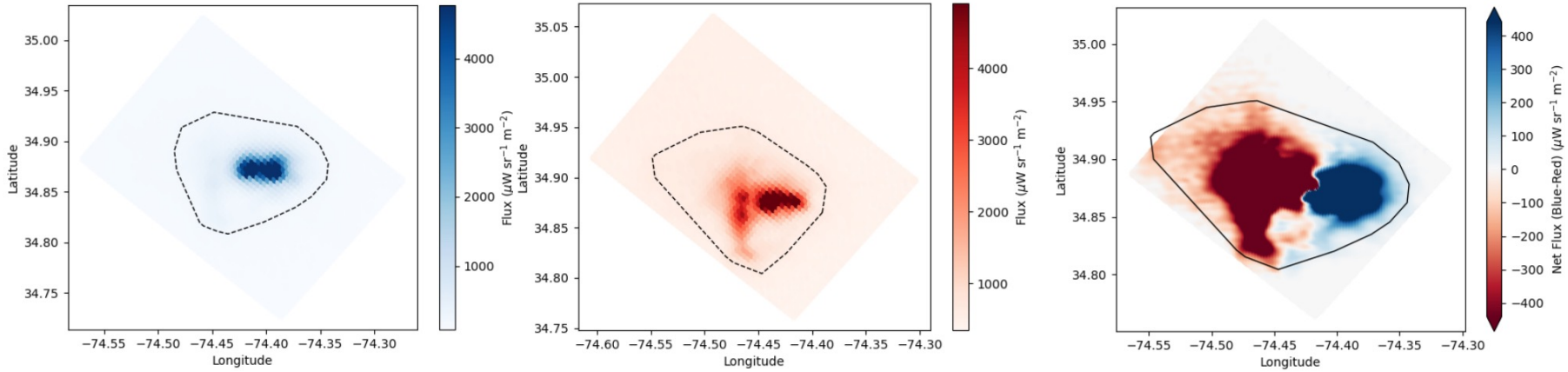
ISS LIS Interdisciplinary Research

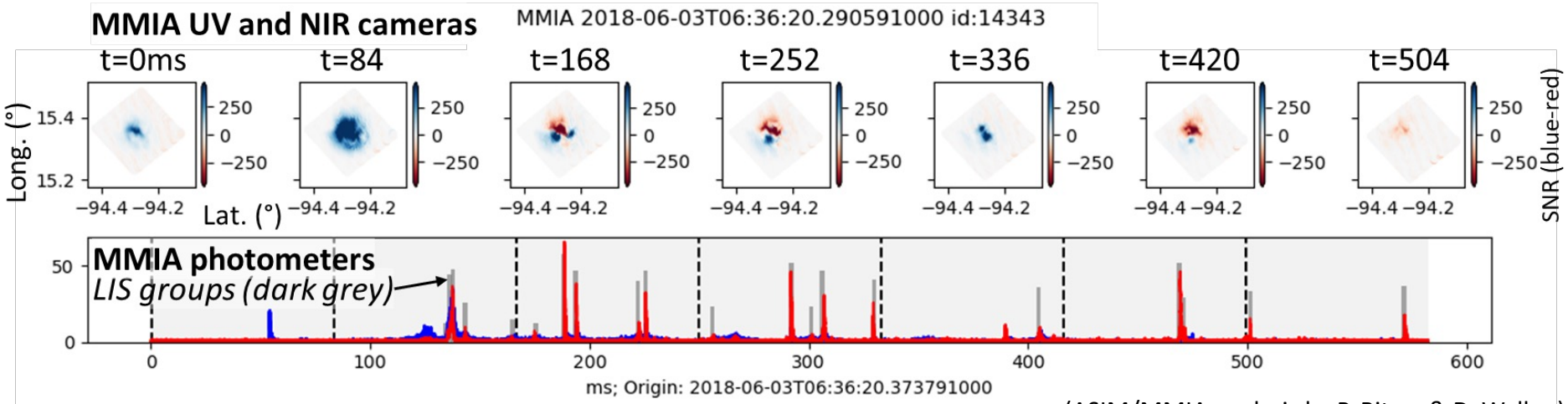
TRMM and ISS LIS viewtime artifacts occur in the vicinity of the South Atlantic Anomaly (SAA), producing a semi-permanent ring and a separate centroid feature

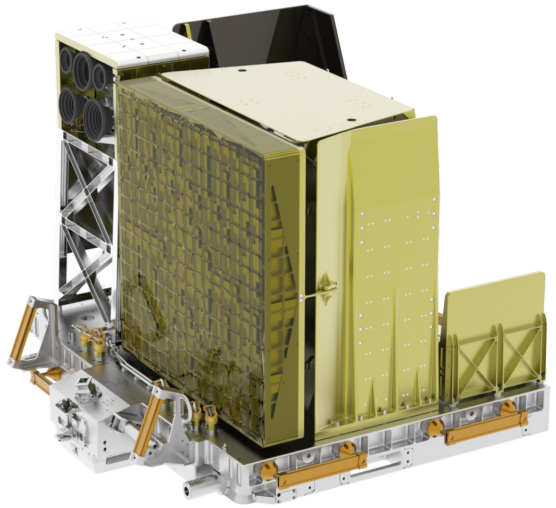
A new project, in collaboration with NASA Goddard, has begun to try to understand this feature



- Comparisons between ISS LIS and the Atmosphere-Space Interactions Monitor (ASIM; also on ISS) show that ASIM's UV spectral channel (337 nm) offers additional information on lightning physics and improves overall detectability of lightning when used in concert with the standard 777-nm (near-IR) channel.







(ASIM/MMIA analysis by P. Bitzer & D. Walker)

ALOFT AND THE FUTURE

Airborne Lighting Observatory for FEGS and TGFs (ALOFT)

FEGS = Fly's Eye Geostationary Lightning Mapper (GLM) Simulator
TGF = Terrestrial Gamma-ray Flash

50-h ER-2 airborne field campaign in July 2023 out of Florida base

Principal Investigator: Nikolai Østgaard, University of Bergen (Norway)
Project Scientist: Timothy Lang, NASA MSFC

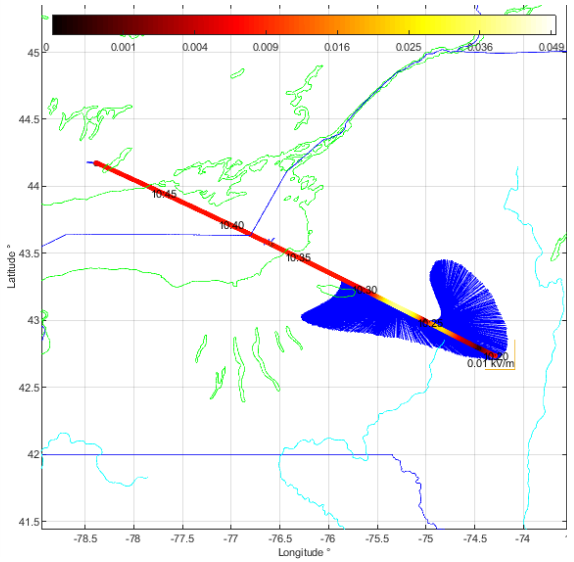
GOALS

1. Observe TGFs in one of the most TGF-intense regions on the planet.
2. Observe gamma-ray glows in thunderstorms and their relation to TGFs.
3. Perform International Space Station Lightning Imaging Sensor (ISS LIS) and GLM validation using improved suborbital instrumentation (including upgraded FEGS).
4. Evaluate new design concepts for next-generation spaceborne lightning mappers.
5. If relevant instrumentation is available, make measurements useful to advance convection science from a suborbital platform.

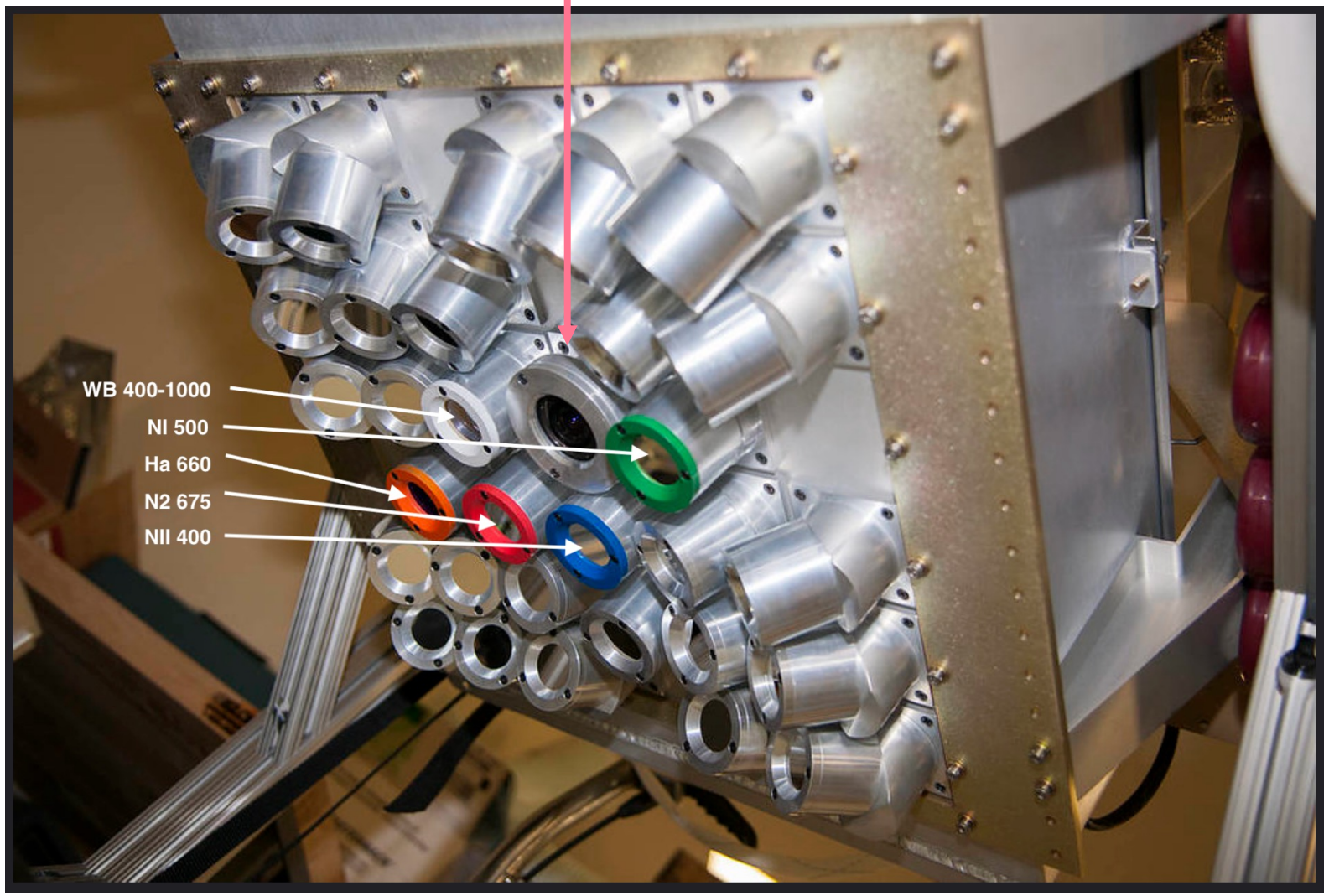
Lightning Instrument Package (LIP)

LIP Measurements

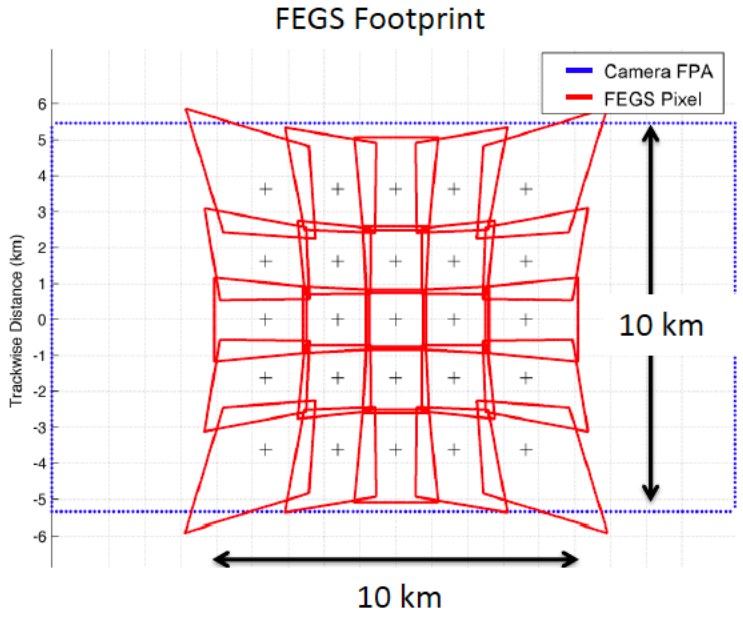
- Instrumentation
  - Electric Field Mills (7)
- Measurements
  - Vector components of the electric field (E_x , E_y , E_z)
  - Aircraft Charge
  - Lightning statistics (identified from electric field changes)
  - Storm electric currents (derived result)
  - Storm charge structure (derived result)
- Measurement Range / Accuracy
  - Electric Field : 1 V/m to 512 kV/m within 5% accuracy



Fly's Eye GLM Simulator (FEGS)



FLY'S EYE
GLM SIMULATOR



Fly's Eye GLM Simulator (FEGS) Upgrade

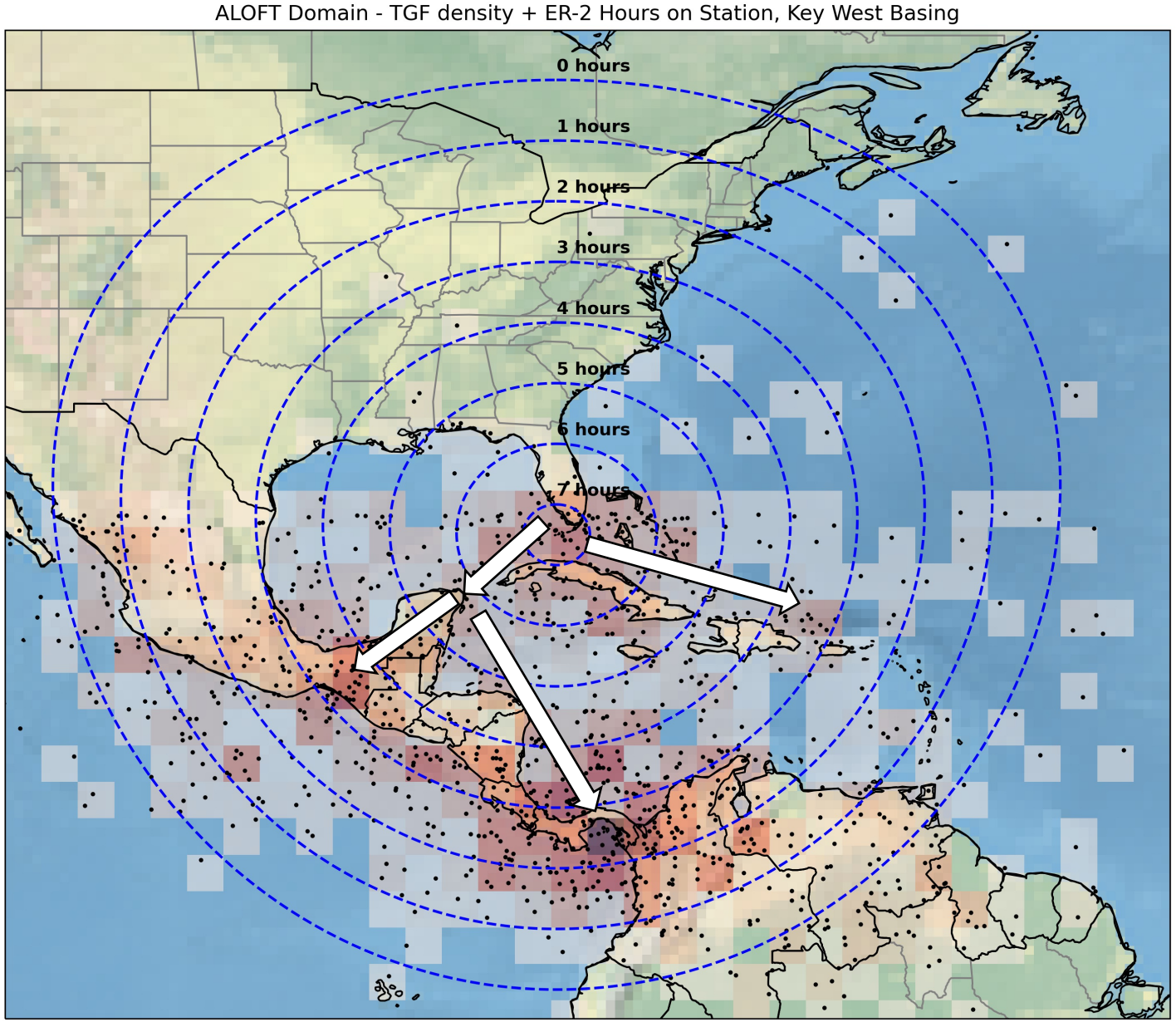
Upgrades planned before July 2023:

Corrections

1. Update electronic gains to improve overall performance (including nighttime functionality)
2. Improve filter on wideband camera to mitigate saturation
3. Improve radiometric precision by mitigating stray light with black paint on metal surfaces

New Functionality

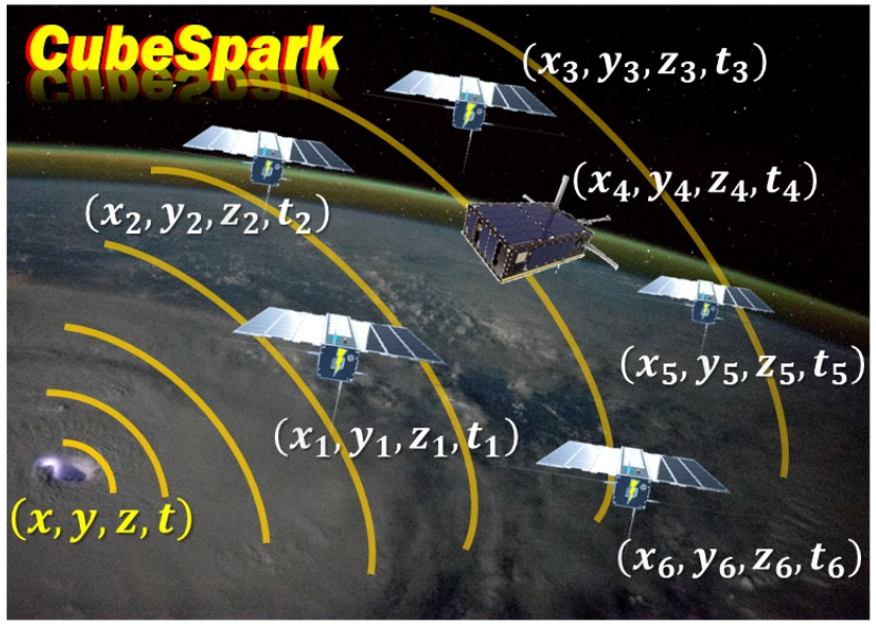
4. Replace the N_2 channel with 337-nm (UV) channel
5. Replace 400-nm channel with 868.3-nm channel (to examine viability as 777-nm alternative)



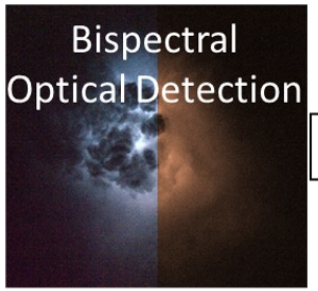
ALOFT Domain
ASIM + GBM detected TGFs (June-September)
Key West ER-2 basing

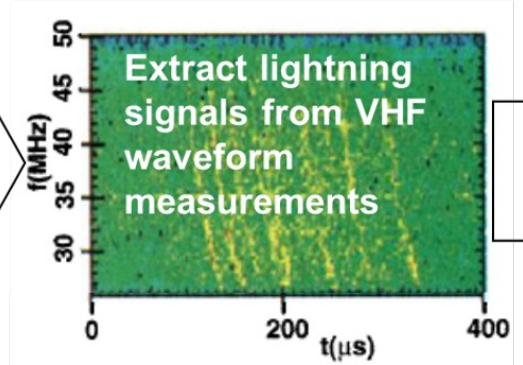
- Great access to Florida/Cuba gap, Puerto Rico area, and Central America
- Regions near Panama and Costa Rica likely accessible for useful science (depends on duration of detour around Cuba)

- CubeSpark is a mission concept being developed by NASA Marshall Space Flight Center and Los Alamos National Laboratory to improve the detection of optically dim flashes and retrieve 3D lightning structure

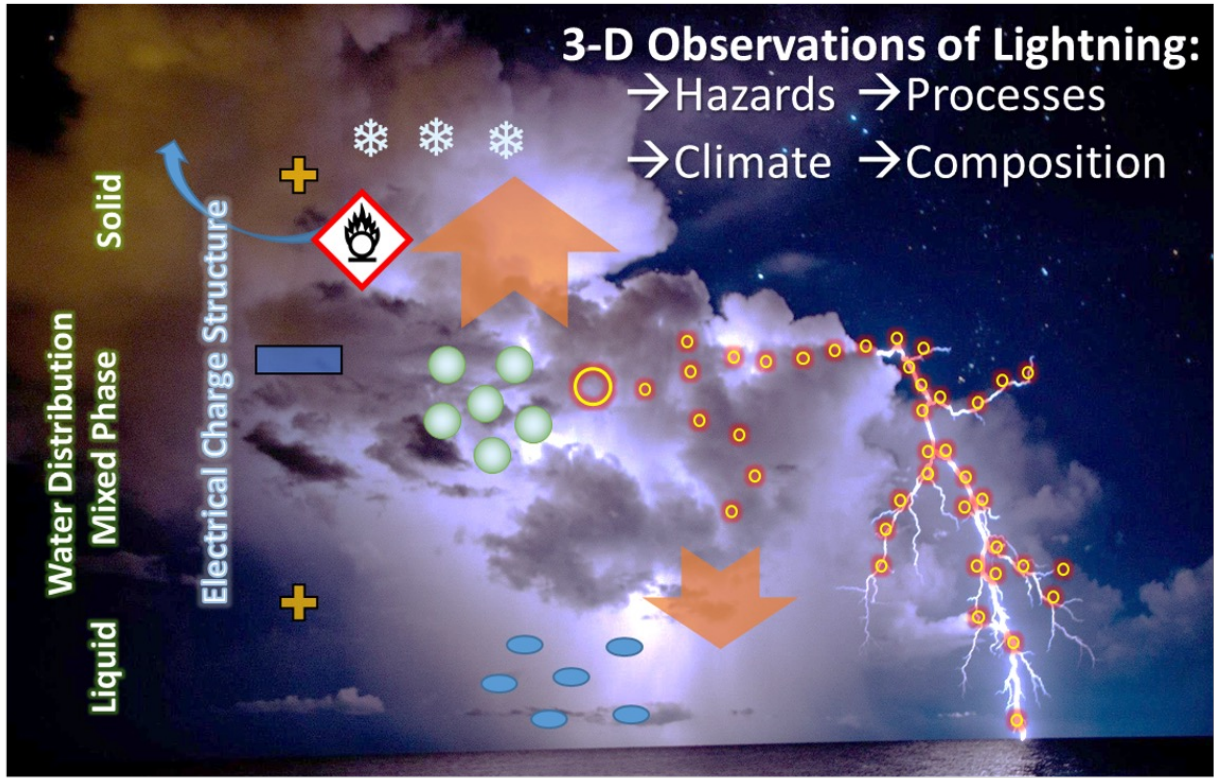


Measurement Concept





Enabled Science and Applications



THANK YOU!