Thunder CATS, Ho! Exploring the scientific utility of combined spaceborne lidar and lightning observations of thunderstorms

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November 22, 2022

Abstract

We will report on the first systematic comparison between global optical lightning measurements and backscatter lidar observations of cloud properties. The results suggest that lidar observations can provide significant insight into the global thunderstorm climatology and also enable new methods for quality control of spaceborne optical lightning observations. The International Space Station Lightning Imaging Sensor (ISS LIS) has been observing thunderstorms between +/-55° latitude since March 2017. During the first ˜8 months of the mission the Cloud-Aerosol Transport System (CATS) lidar was co-located with LIS on the ISS. CATS provided vertical profiles of cloud and aerosol properties along a nadir curtain. For thunderstorms, CATS observations enabled retrieval of cloud-top height, the presence of liquid water vs. ice, and other important cloud properties that are relevant to the production of lightning. Through systematic comparison of ISS LIS and CATS granules, over 8000 LIS-detected flashes were matched with nearby coincident CATS profiles between 1 March and 30 October 2017. All of these flashes' centroids were within 25 km of the CATS laser's ground track. Two-dimensional histograms of cloud-top height and latitude show consistency with the expected global behavior of thunderstorm height – namely, that storm heights are constrained by the tropopause, which slopes downward toward the poles. The observed CATS/LIS trend was found to be consistent with long-term March-October thunderstorm 20-dBZ echo-top height climatologies derived from the Tropical Rainfall Measuring Mission (TRMM) and the Global Precipitation Measurement (GPM) mission (the latter combined with Worldwide Lightning Location Network data). However, the radar-based climatologies indicate that 20-dBZ echo tops average ˜2 km lower in altitude compared to lidar-inferred cloud tops. The CATS lidar also enabled identification of potential LIS false alarms (FAs). Additional analyses, including lidar-inferred ice-cloud properties in thunderstorms (e.g., ice-water content), will be presented. Overall, this pathfinder study with a limited ˜8-month dataset suggests that fruitful scientific insights may be expected from potentially larger combined lidar/lightning datasets.

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Why Combine Lightning with Lidar?

Benefits

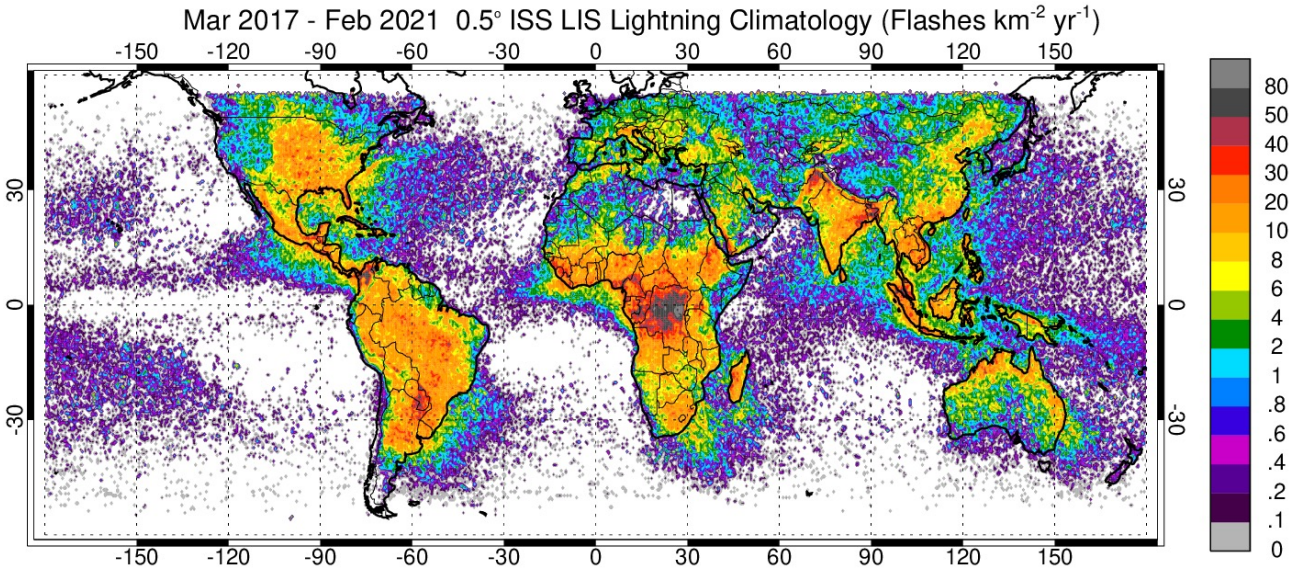
- Lidar provides a more accurate measure of cloud-top height than, e.g., radar
- Lidar can be used to infer cloud microphysics (phase, etc.)
- Lidar can infer some vertical structure in clouds
- Lidar can detect and categorize aerosols
- Lidars have been in orbit for more than a decade (e.g., CALIOP), like spaceborne lightning observations, and are expected to continue (e.g., AOS)

Challenges

- Lidar typically measures a nadir curtain, while spaceborne lightning observations are horizontally distributed
- Lidar does not penetrate thick clouds
- No well-tread analysis pathways (e.g., like radar/lightning)

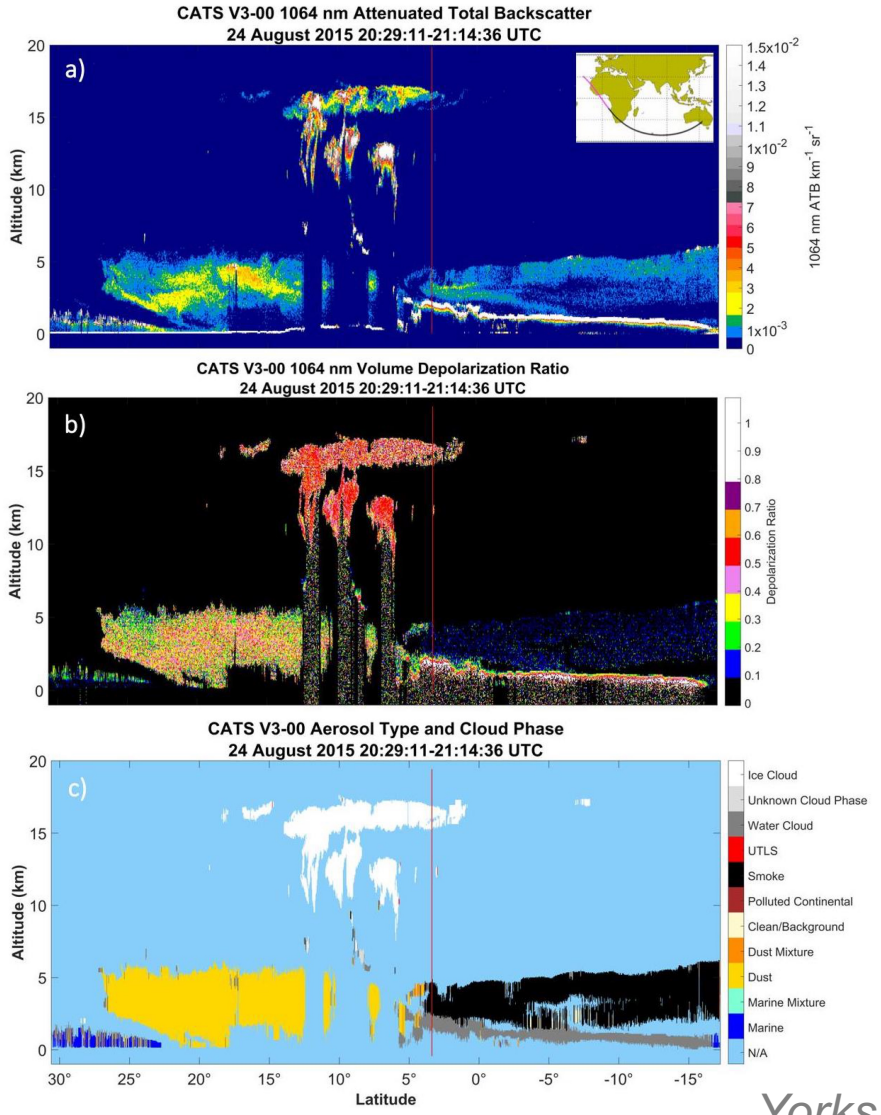
ISS LIS Overview

- The International Space Station Lightning Imaging Sensor (ISS LIS) is a high-speed camera that detects lightning via monitoring transients at 777.4 nm
- Modified TRMM LIS (1997-2015) flight spare hosted within DoD STP-H5, launched in 2017
- ISS LIS extends TRMM LIS time series observations, expands latitudinal coverage, provides real-time data to operational users, and enables cross-sensor calibrations (e.g., GLM)



Adapted from Blakeslee et al. (2020)

CATS Overview



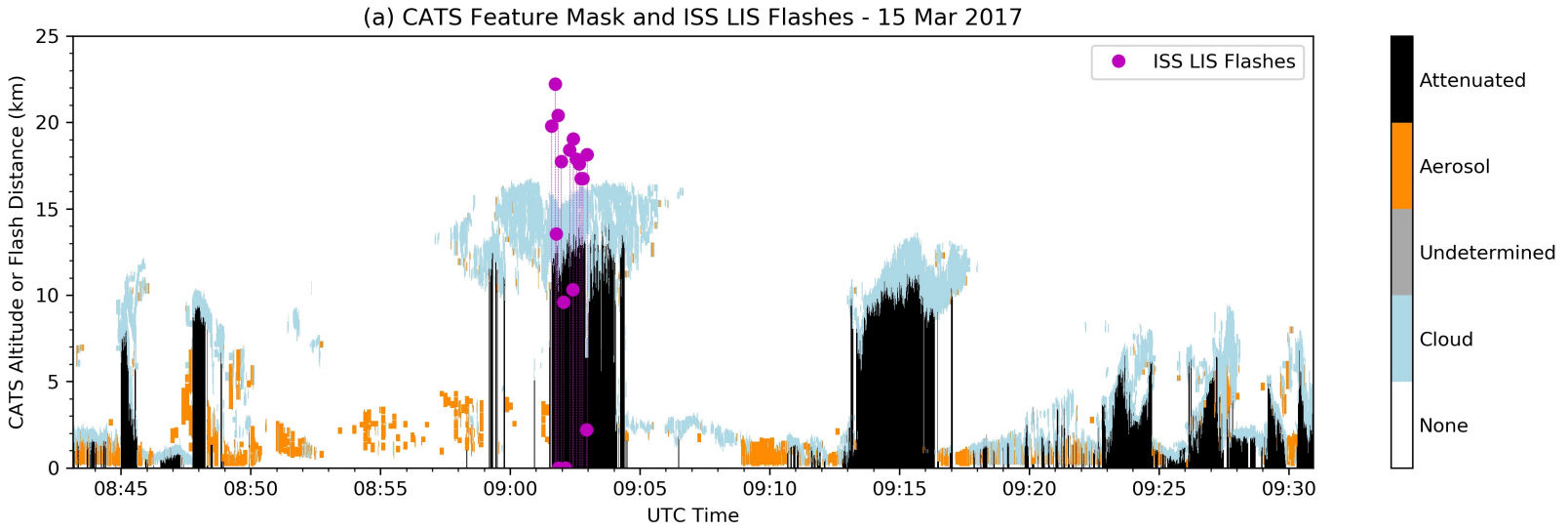
- Cloud-Aerosol Transport System (CATS; 2015-2017) lidar made range-resolved measurements of clouds and aerosols at 1064 and 532 nm (355-nm mode failed)
- Level 2 products include vertical feature mask (e.g., liquid vs. frozen, aerosol type), profiles of cloud and aerosol properties (e.g., particle backscatter), and layer-integrated parameters (e.g., lidar ratio)
- Overlapped on ISS with LIS during March-October 2017 (Trivia: CATS ray-tracing code adapted and used within ISS LIS geolocation routines)

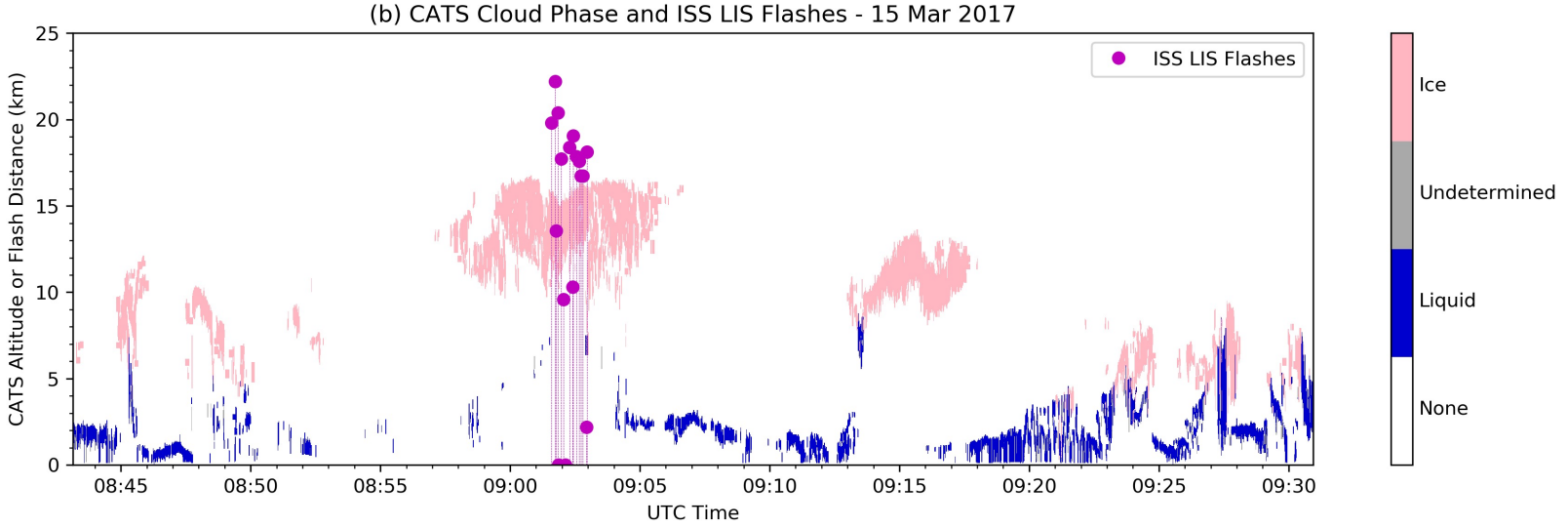
Yorks et al. (2021)

Methodology

- Examine 1 March thru 29 October 2017 period (LIS/CATS overlap)
- 8246 ISS LIS flashes identified that have centroids within 25 km of CATS ground track
- Automated statistical analysis of cloud properties near lightning (+/- 50 km along CATS track; e.g., cloud-top height, etc.)
- Manual review of combined LIS/CATS quicklooks
- Daytime matchups also checked using geolocated ISS LIS backgrounds (https://github.com/nasa/ISS_Camera_Geolocate)

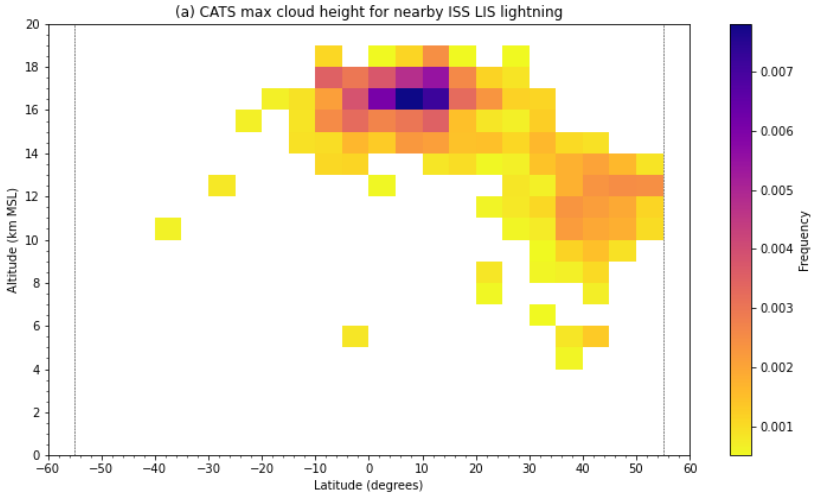
Matchup Example



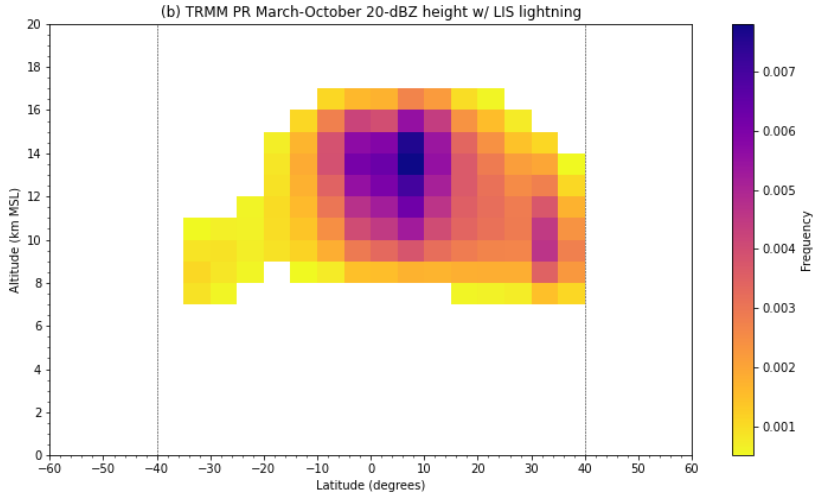


Cloud-Top Climatology

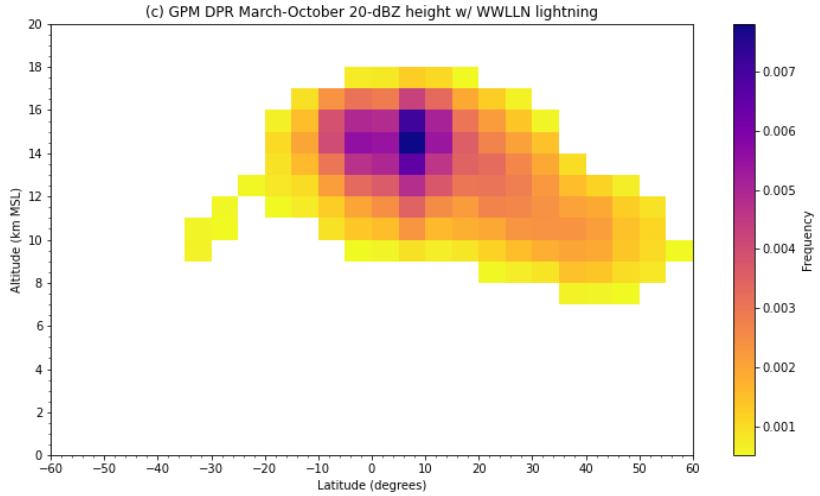
CATS + ISS LIS



TRMM

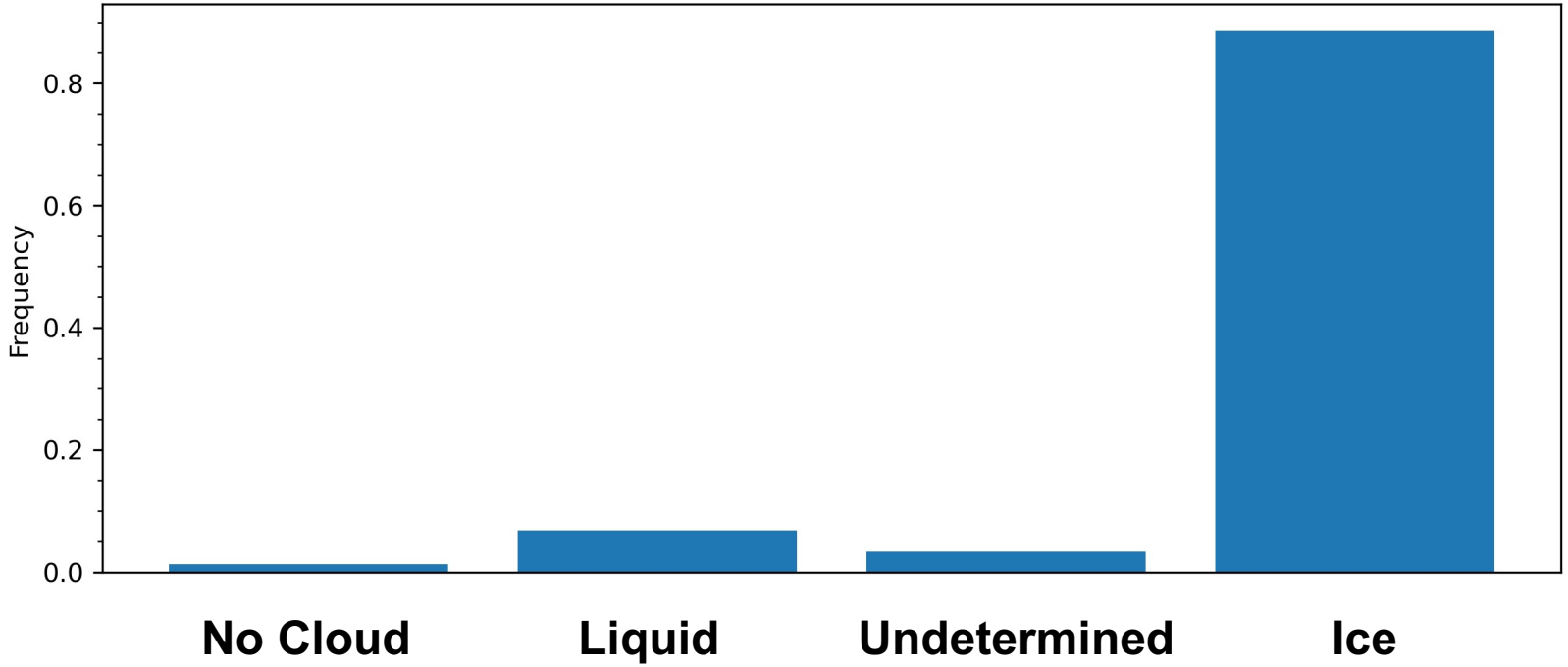


GPM + WWLLN



- TRMM and GPM precipitation radars combined with TRMM LIS and WWLLN observations, respectively
- CATS cloud-top heights maximized in tropics and descend toward midlatitudes, as expected
- Radar 20-dBZ echo-top heights have similar distribution but average approximately 2 km lower than CATS cloud-top heights

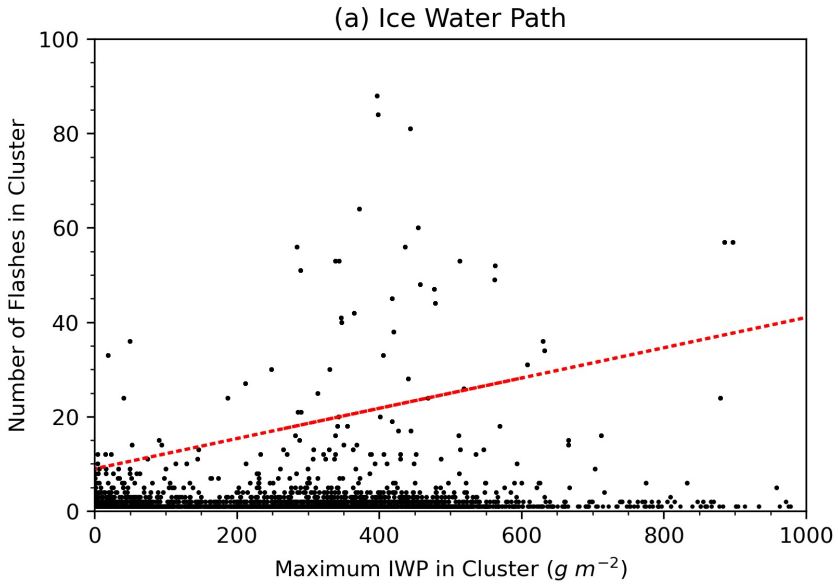
Lightning vs. Cloud Phase



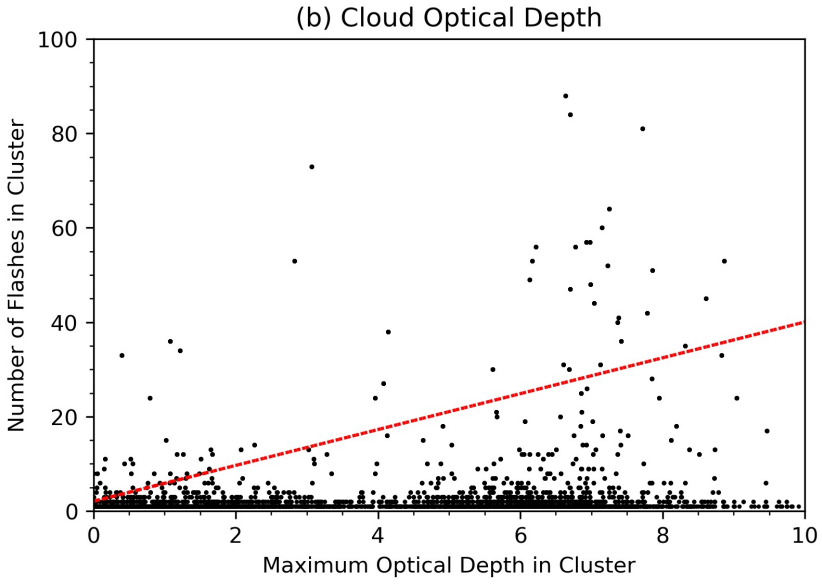
- CATS can distinguish liquid water vs. ice phase within observed cloud
- 91.9% of profiles with lightning associated with ice-phase or undetermined (likely mixed-phase) cloud
- 6.8% of profiles associated with liquid cloud
- Suggests CATS can identify cloud ice with 90%+ accuracy

Lightning vs. Cloud Properties

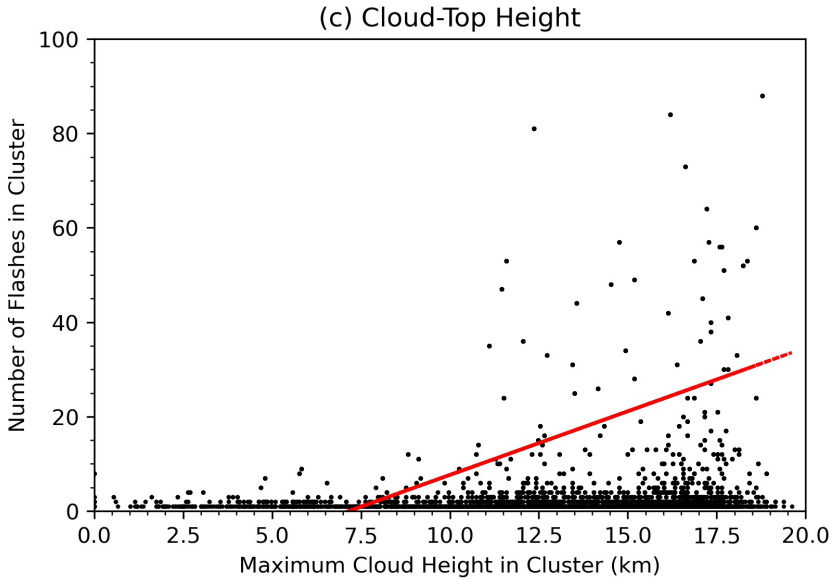
Flashes vs. IWP



Flashes vs. Optical Depth



Flashes vs. Cloud-Top Height

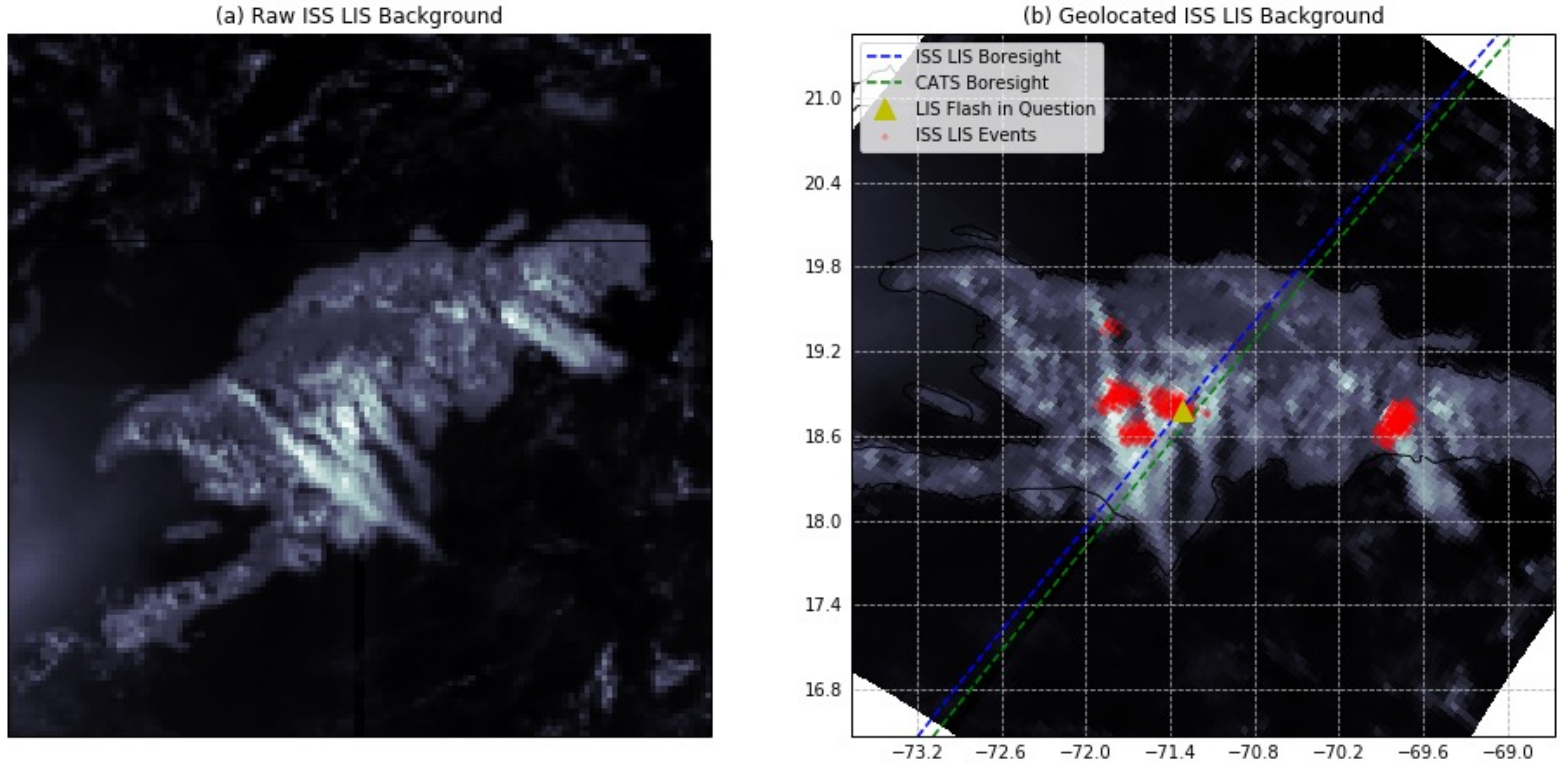


- Use DBSCAN to cluster flashes within +/- 50 km
- Compare number of flashes in cluster to max CATS retrieval values
- All best-fit line (red) correlations ~0.38-0.42, p << 0.01

False Alarm Analysis

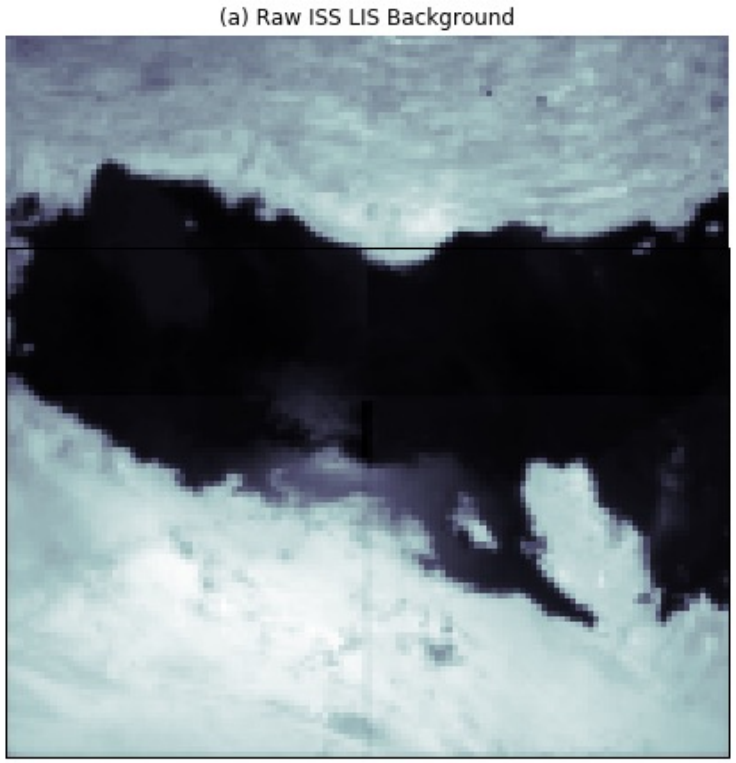
- Blakeslee et al. (2020) reported an ISS LIS false alarm rate (FAR) under 5%, based on comparisons with other reference lightning datasets
- Of the 8246 LIS/CATS matchups, 105 (1.3%) have no CATS-identified cloud within 25 km of flash centroid
- 65 of these candidate false alarms occurred during daytime and have nearly coincident ISS LIS backgrounds
- Manual review of these geolocated backgrounds found only 6 instances where there were no apparent clouds in the LIS backgrounds, suggesting surface glint FAR for ISS LIS is ~0.1%

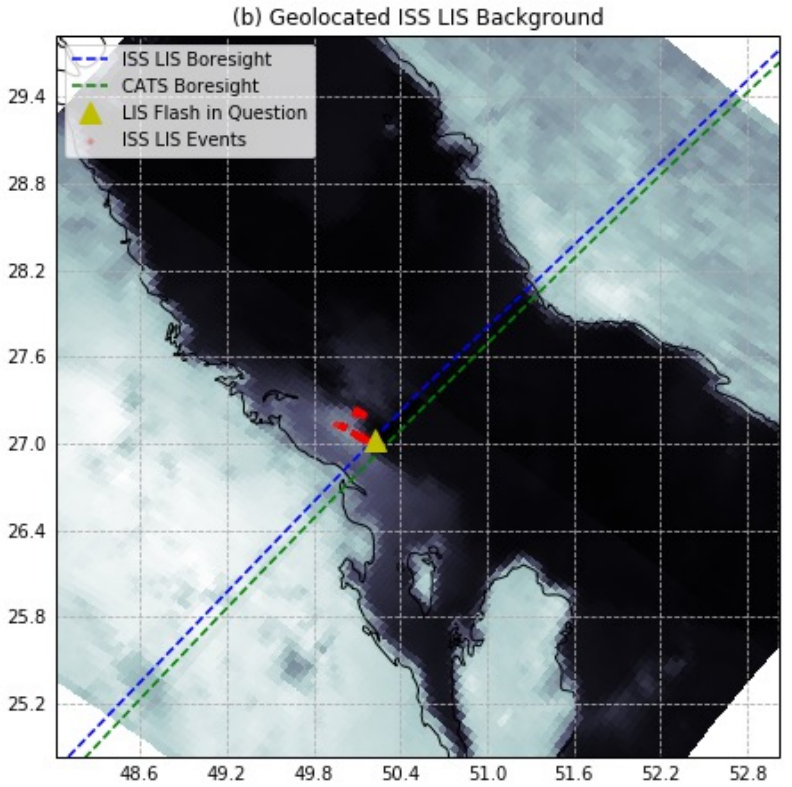
Comparison with LIS Backgrounds – Lidar "Mistake"



- Vast majority of candidate FAs are similar to this, where obvious convection (in this case, over Hispaniola) is in the LIS FOV and lightning is reasonable
- Either analysis limitation or possible CATS data issue – have not fully explored QC flags

Comparison with LIS Backgrounds – LIS Mistake





- Very small number of FA candidates are like this, which appears to show glint from the surface (in this case, the Persian Gulf) made it through LIS data filters

Summary

- Lidar observations provide insight into the global thunderstorm climatology and enable new methods for quality control of spaceborne optical lightning observations
- Radar-based climatologies indicate that 20-dBZ echo tops average ~2 km lower in altitude compared to lidar-inferred cloud tops
- Lightning shows reasonable behavior relative to lidar-retrieved cloud properties (e.g., phase, optical depth, IWP, etc.)
- The false alarm rate for LIS-identified flashes associated with no nearby cloud (e.g., solar glint off water) is ~0.1%
- Fruitful scientific insights are expected from larger combined lidar/lightning datasets (GLM/CALIOP) or potential future datasets (e.g., GeoXO/AOS)

ISS LIS Plugs

- Version 2 data are now available at the GHRC DAAC. Improved viewtime estimates and more!

- Other LIS-related AGU presentations
  - **Tiberia** (AE15A-1884) – “Investigation of Lightning Distributions over Mt. Cimone using LINET and ISS-LIS Data for the Gamma-Flash Program”, Monday 12/13 @ 4-6p
  - **Stano** (AE15B-1893) – “Lightning Activities at the Global Hydrometeorology Resource Center Distributed Active Archive Center”, Monday 12/13 @ 4-6p
  - **Ren** (AE15B-1898) – “Intracloud to Cloud-to-Ground Lightning Ratio over China and Its Relationship with Thunderstorm Structure”, Monday 12/13 @ 4-6p
  - **Montanya** (AE25A-1918) – “Lightning Mapping Array and space-based optical observations of Narrow Bipolar Events”, Tuesday 12/14 @ 4-6p
  - **Zhang** (AE34A-01) – "Fusing GEO and LEO Lightning Observations”, Wednesday 12/15 @ 2:32p
  - **Quick** (AE34A-02) – “A calibration baseline for lightning radiometry from space”, Wednesday 12/15 @ 2:41p
  - **Bitzer** (AE35A-1905) – “Multifrequency optical observations of lightning with ISS-LIS and ASIM”, Wednesday 12/15 @ 4-6p

- NASA is seeking input on research related to lightning’s effects beyond Earth’s troposphere: https://TinyURL.com/NASALightning; Virtual workshop on this topic planned for 2-3 May 2022