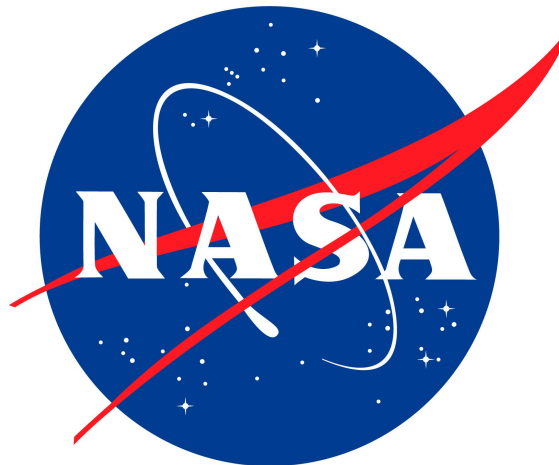
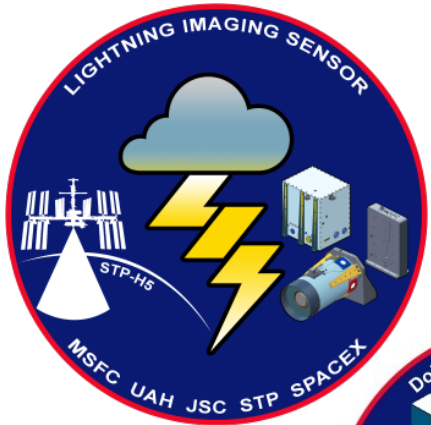


Thunder CATS, Ho! Exploring the scientific utility of combined spaceborne lidar and lightning observations of thunderstorms

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Why Combine Lightning with Lidar? ISS | Earth Science

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)

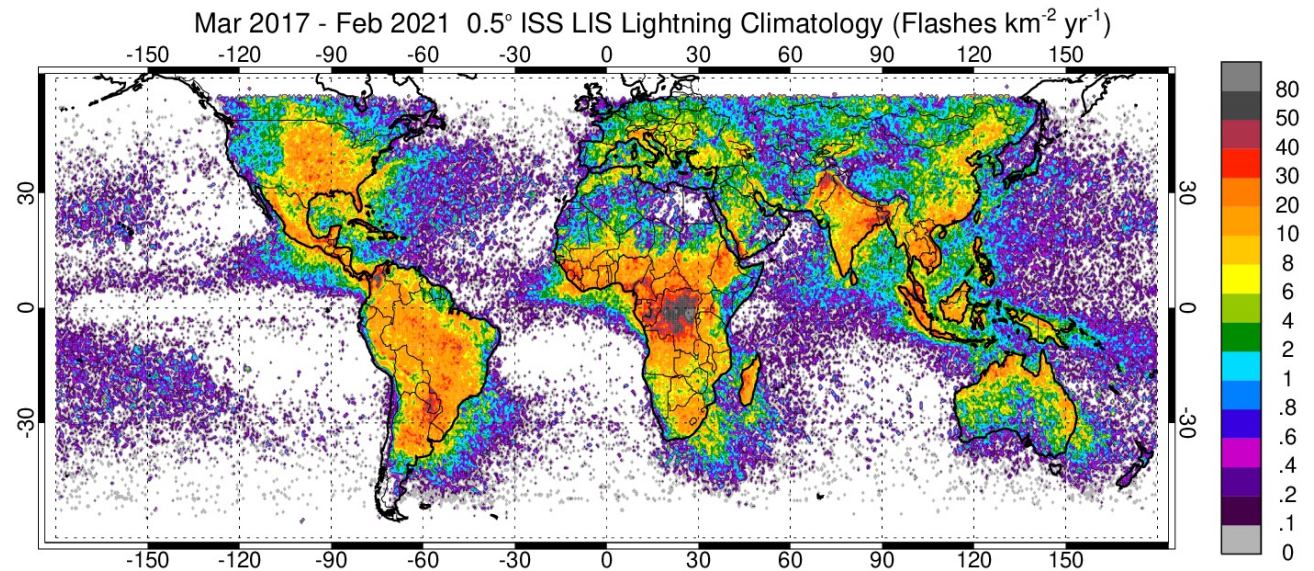




ISS LIS Overview

ISS | Earth Science

- 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)



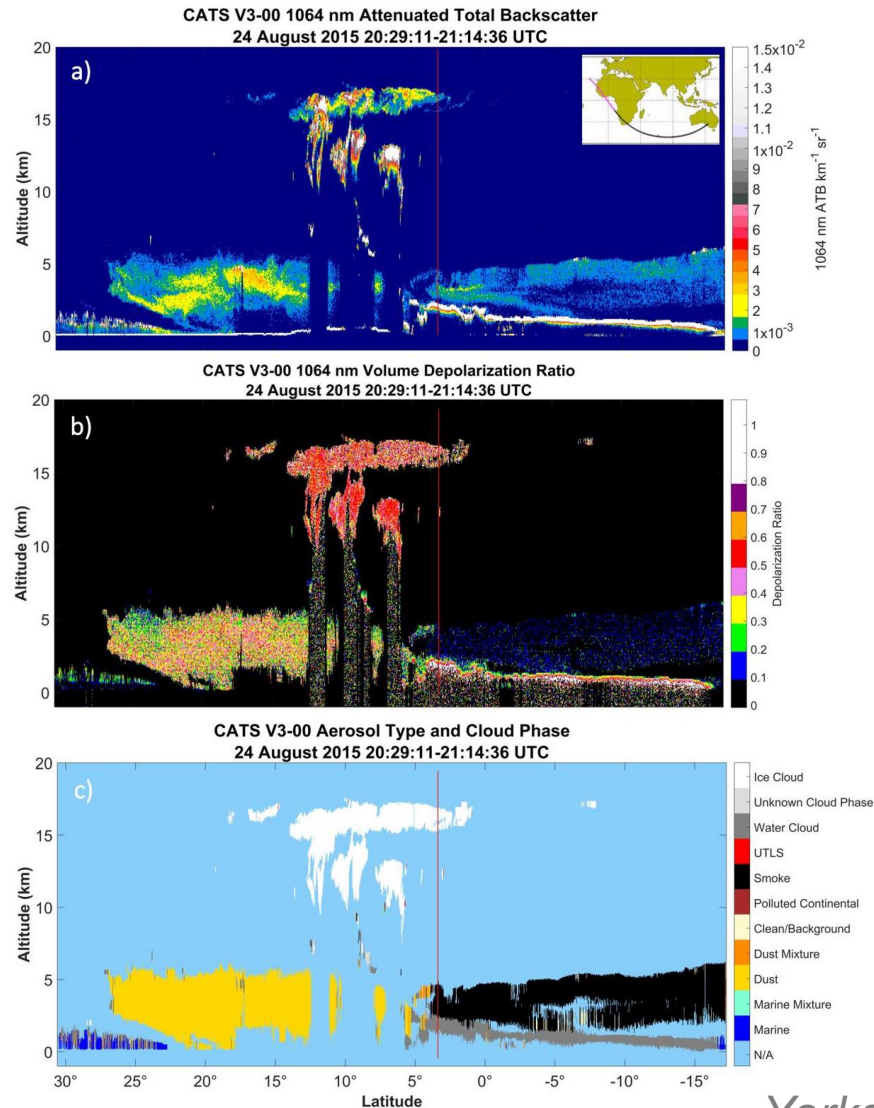
Adapted from Blakeslee et al. (2020)





CATS Overview

ISS | Earth Science



- 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)





- 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)

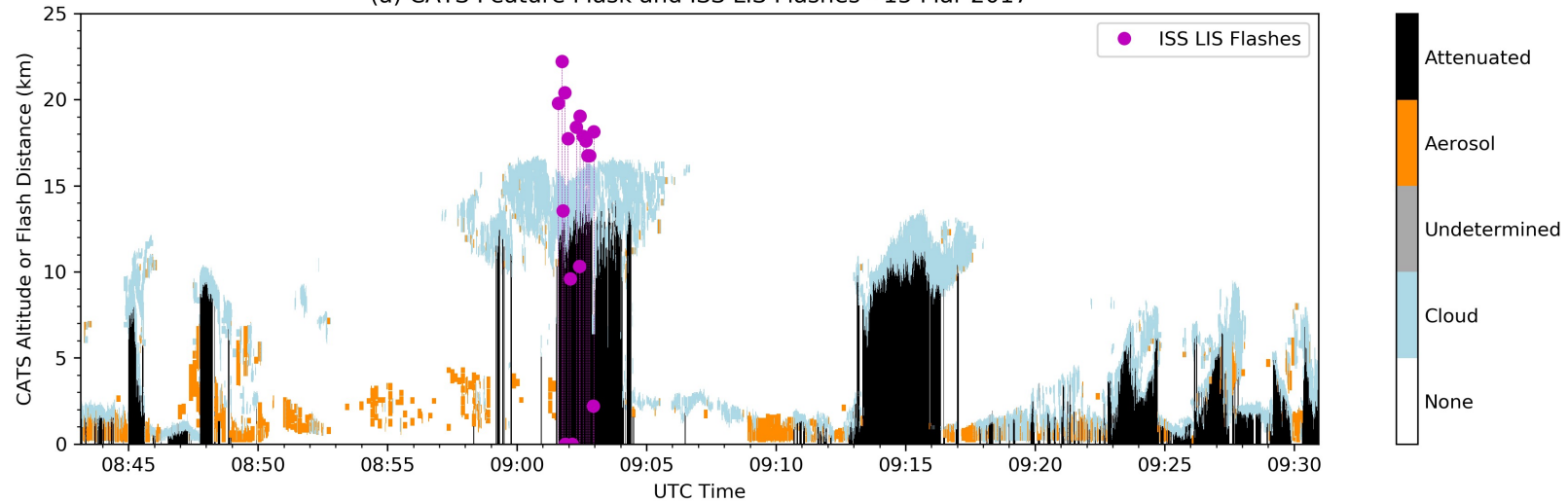




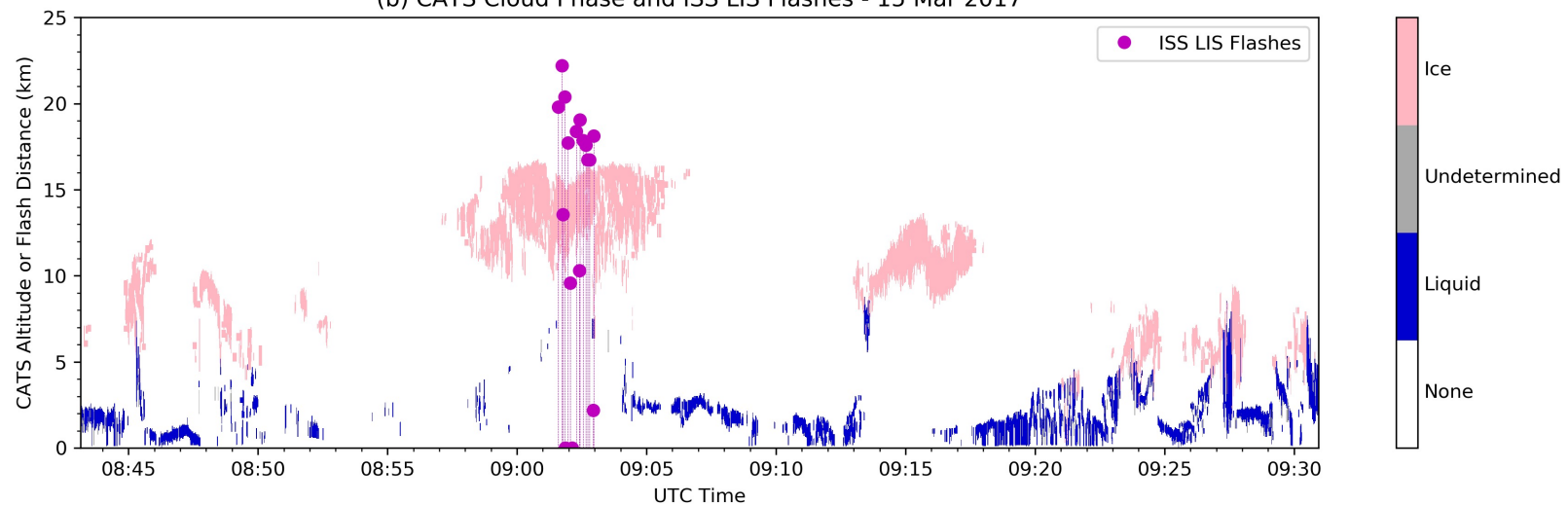
Matchup Example

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(a) CATS Feature Mask and ISS LIS Flashes - 15 Mar 2017



(b) CATS Cloud Phase and ISS LIS Flashes - 15 Mar 2017

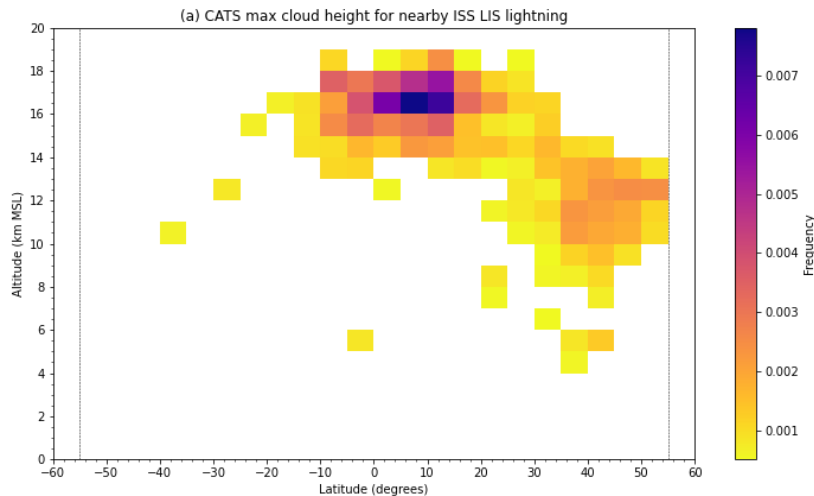




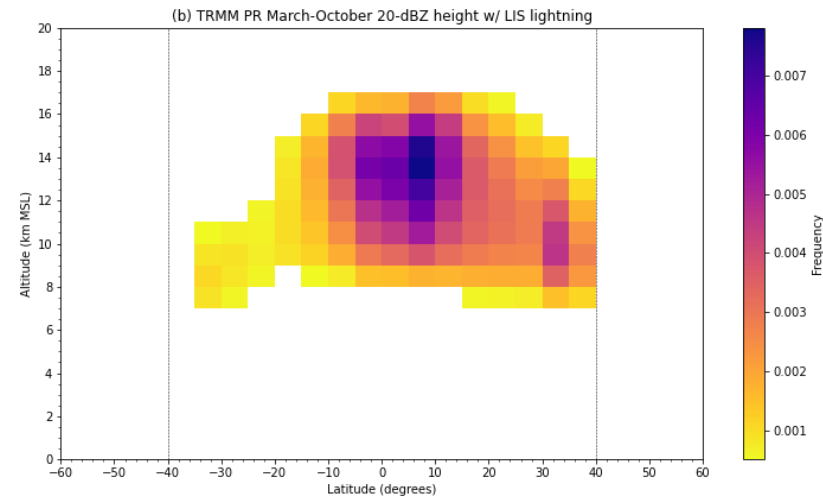
Cloud-Top Climatology

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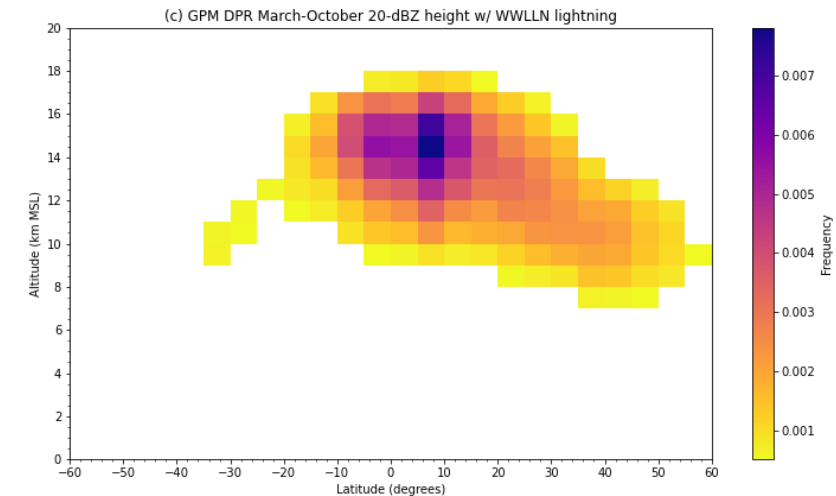
CATS + ISS LIS



TRMM



GPM + WWLLN



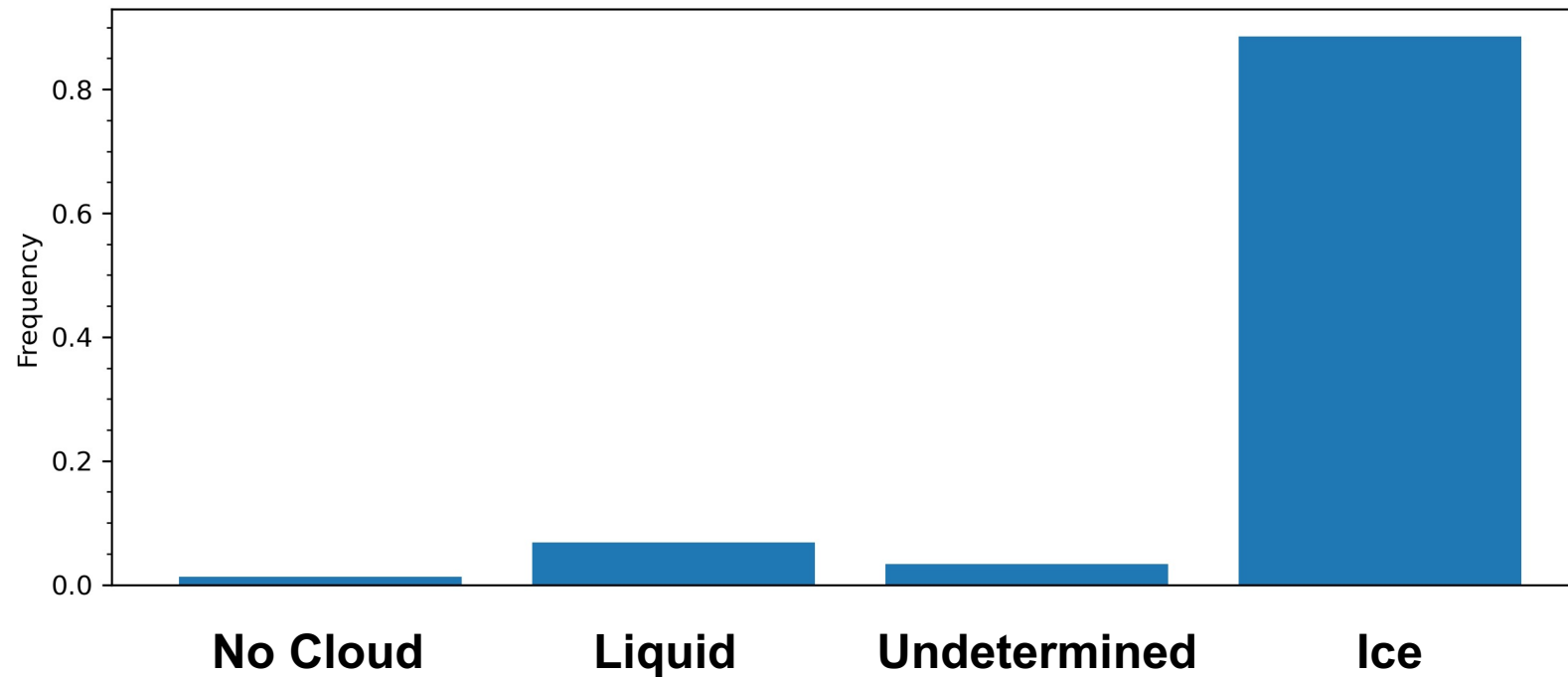
- TRMM and GPM precipitation radars combined with TRMM LIS and WWLLN observations, respectively
- CATS cloud-top heights maximized in tropics and descend toward midlatitudes, as expected
- Radar 20-dBZ echo-top heights have similar distribution but average approximately 2 km lower than CATS cloud-top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





Lightning vs. Cloud Phase

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- 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

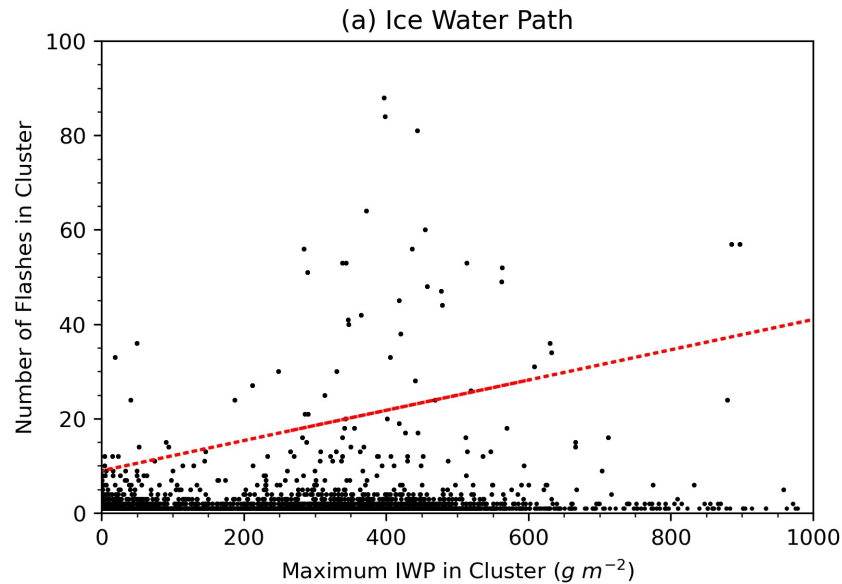




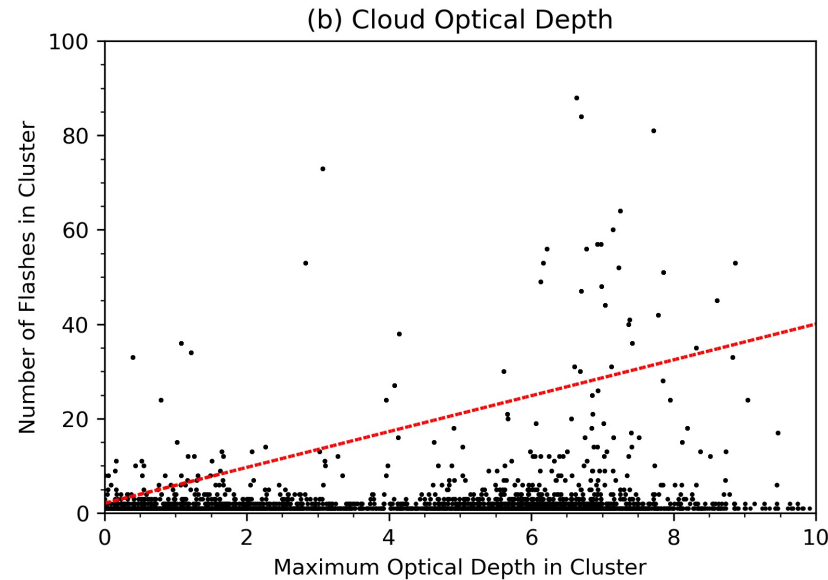
Lightning vs. Cloud Properties

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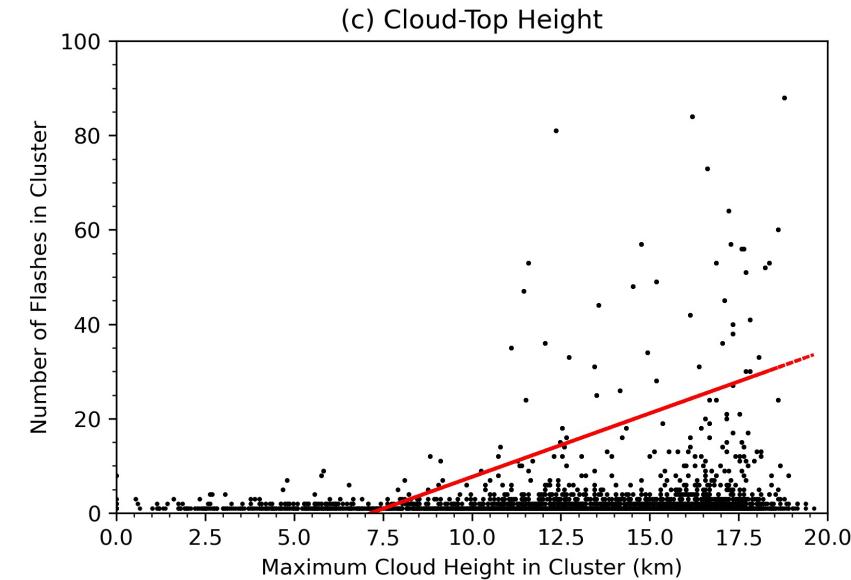
Flashes vs. IWP



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, $p \ll 0.01$





False Alarm Analysis

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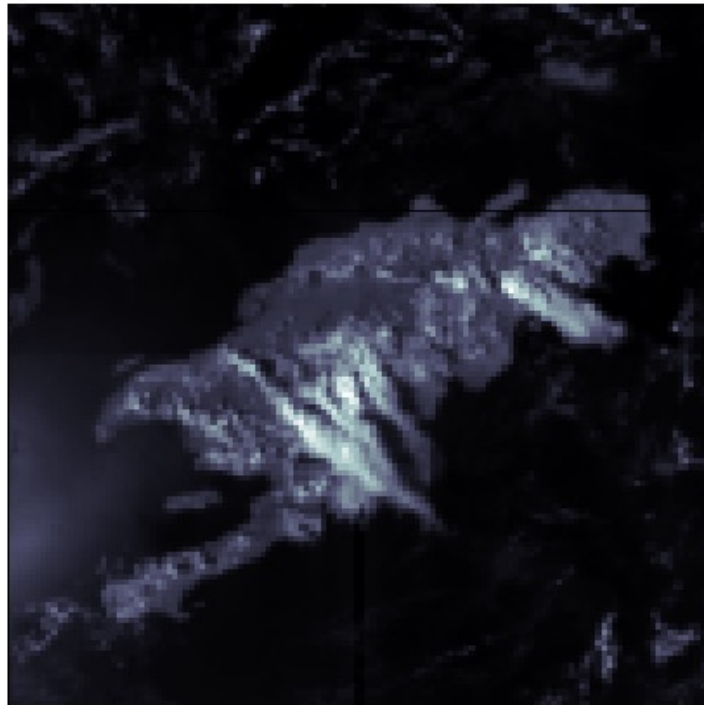
- Blakeslee et al. (2020) reported an ISS LIS false alarm rate (FAR) under 5%, based on comparisons with other reference lightning datasets
- Of the 8246 LIS/CATS matchups, 105 (1.3%) have no CATS-identified cloud within 25 km of flash centroid
- 65 of these candidate false alarms occurred during daytime 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 $\sim 0.1\%$



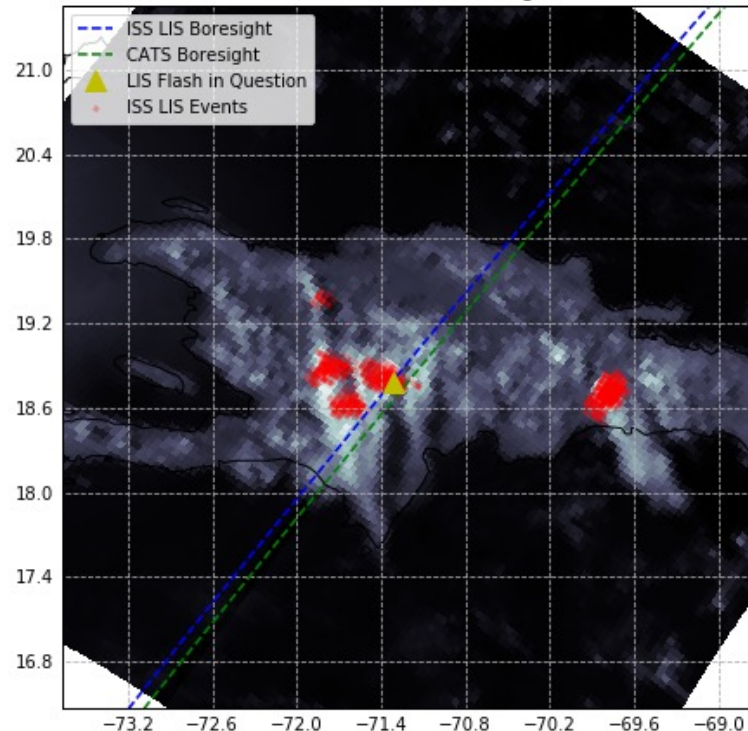
Comparison with LIS Backgrounds – Lidar “Mistake”

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(a) Raw ISS LIS Background



(b) Geolocated ISS LIS Background



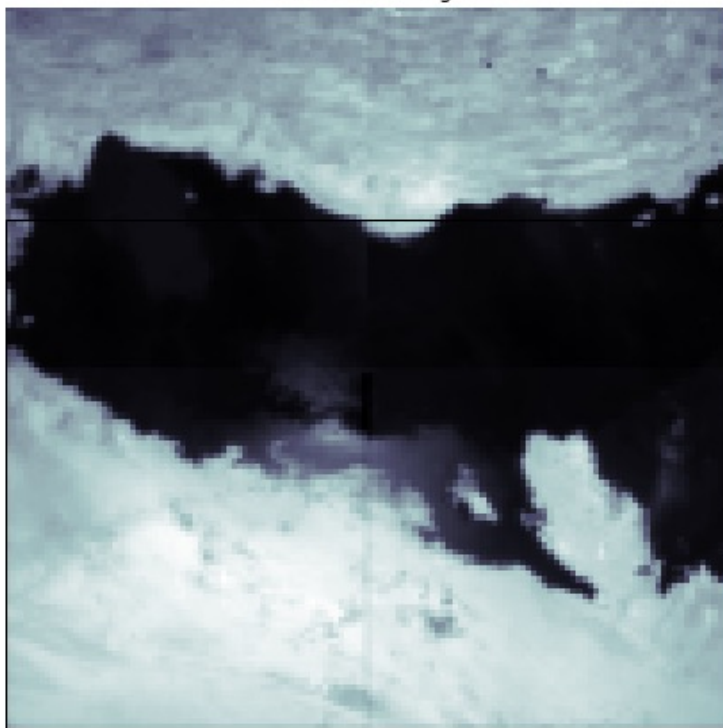
- Vast majority of candidate FAs are similar to this, where obvious convection (in this case, over Hispaniola) is in the LIS FOV and lightning is reasonable
- Either analysis limitation or possible CATS data issue – have not fully explored QC flags



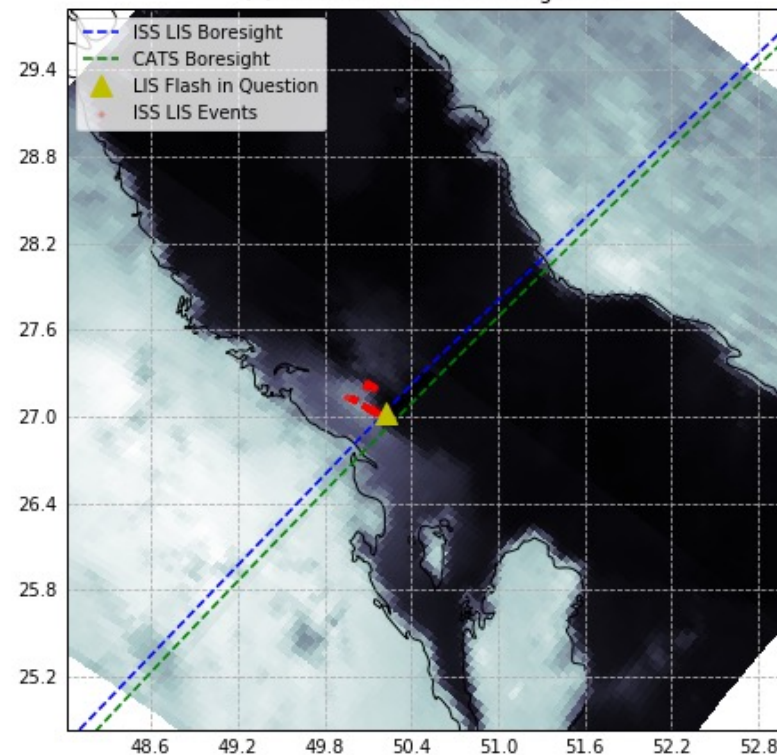
Comparison with LIS Backgrounds – LIS Mistake

ISS | Earth Science

(a) Raw ISS LIS Background



(b) Geolocated ISS LIS Background



- 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 filter





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 $\sim 0.1\%$
- Fruitful scientific insights are expected from larger combined lidar/lightning datasets (GLM/CALIOP) or potential future datasets (e.g., GeoXO/AOS)



ISS LIS Plugs

ISS | Earth Science

- 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

