Update on Radio Frequency Sensor: 3.5 Years of RF Lightning Detection from GEO

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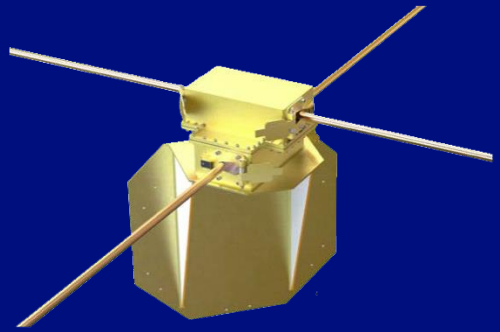
Radio Frequency Sensor : RF Lightning detection at GEO

Recap

- First time for RF lightning detection in GEO
- Launched 6 December 2021: Turn-on 15 January; Operational mode: 20 February 2022
- Triggers on broadband radio frequency transients from lightning
- Millions of lightning events captured so far



Top updates

Two recent RFS papers

- Pailoor et al. (2025). Statistical analysis of trans-ionospheric pulse pairs and inferences on their characteristics. *J. of Geophys. Res.: Atmos.,* https://doi.org/10.1029/2025JD043403
- Nag et al. (2025) Radio Frequency Transients Correlated with Electron Flux Measured On-Board the STP-Sat6, *Adv. in Space Res.*, https://doi.org/10.1016/j.asr.2025.07.026

Data set for public release is in progress

Signals detected by RFS

- Lightning processes that produce intense VHF emissions survive trans-ionospheric propagation and are detected by the RFS.
- The most commonly detected lightning from space are compact intracloud discharges (CID) or narrow bipolar events (NBE).
- The signature of CIDs detected from space is comprised of two pulses due to the direct (source-to-spacecraft) and reflected (source-earth-spacecraft) propagation paths called trans-ionospheric pulse pairs (TIPPs).
- Another commonly detected RF signature by the RFS is that of transient “discharges” occurring in-situ in/around the spacecraft called on board discharges (OBDs) or spacecraft environment discharges (SEDs).

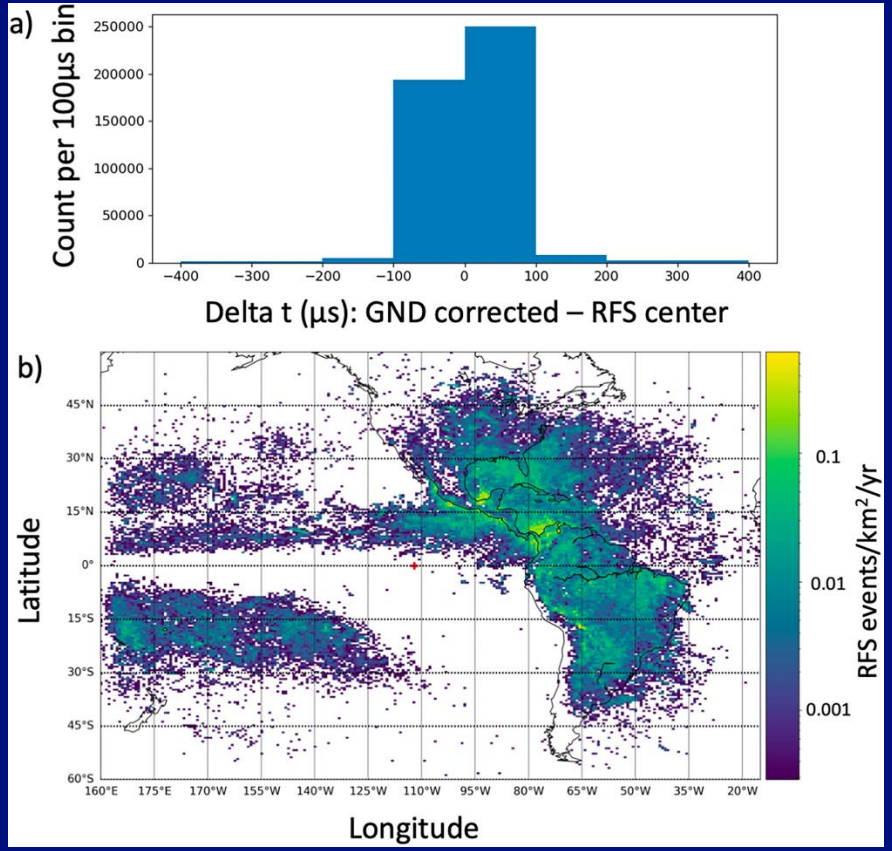
Locations of RFS/ENTLN matches: need location for TIPP-height calculation

Table 1
Total Counts of RFS Events and RFS Coincidences With Other Lightning Location Data Sets During the Time Period of 1 March 2022–1 March 2023

	Total counts	Percentage
All RFS w/TEC ≥ 5 TECU	4,97,327	---
ENTLN coinc (100 us)	4,52,336	91.0
WWLLN coinc (100 us)	2,28,084	45.9
ENTLN or WWLLN coinc	4,70,012	94.5
GLM coinc (2 ms)	3,84,174	77.2
GLM only coinc (2 ms)	23,484	4.7

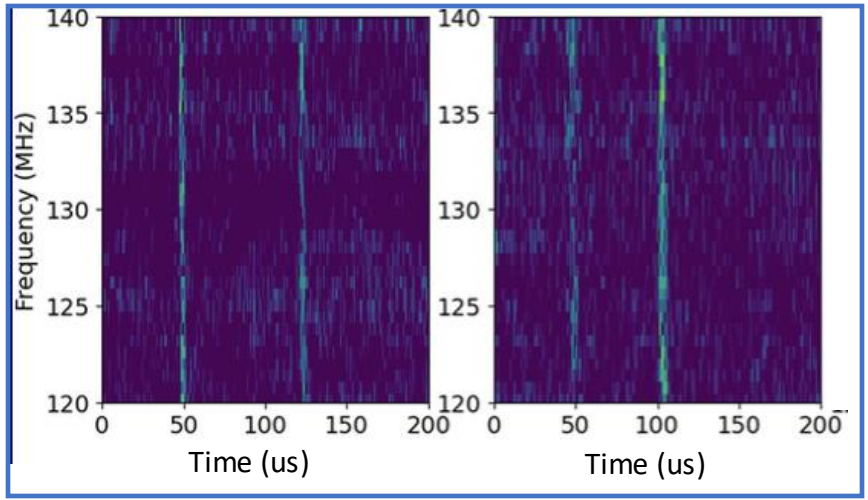
Note. Right column shows percentages.

[Lay et al., Radio Science, *doi:10.1029/2023RS007931*]



Transionospheric Pulse Pairs (TIPPs) Case Study 06/01/2023

- 85-90% of RFS detections are TIPPs (found to correspond to CIDs, NBEs)
- Machine learning to automatically identify thousands of TIPPs
- Time difference + geolocation gives altitude
- Can track storm development in height with TIPPs



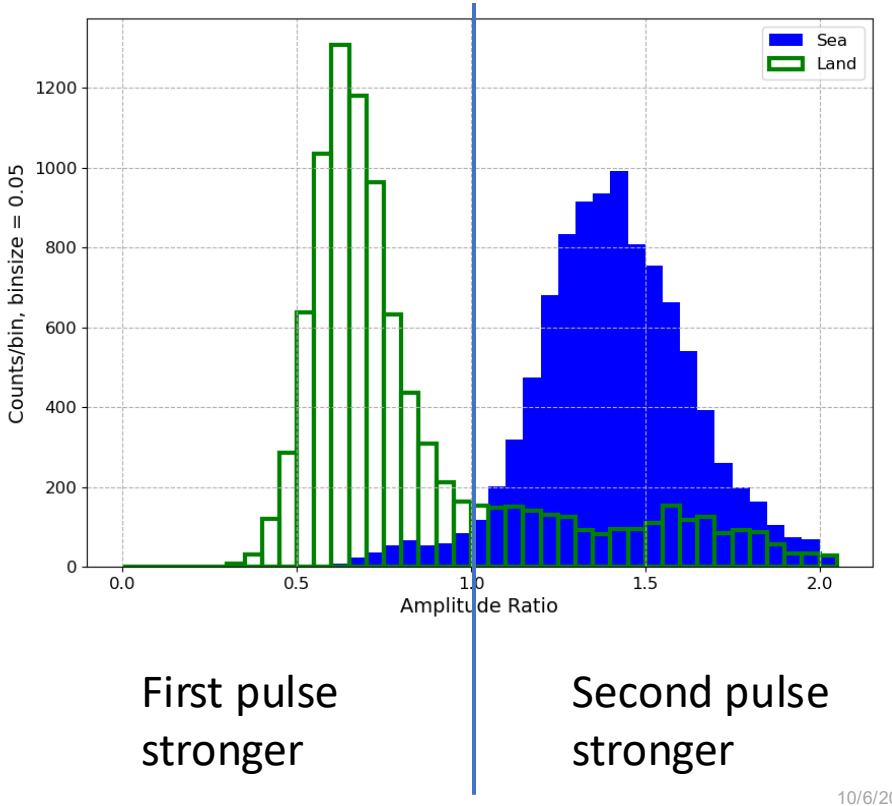
First pulse stronger

Second pulse stronger

Why???

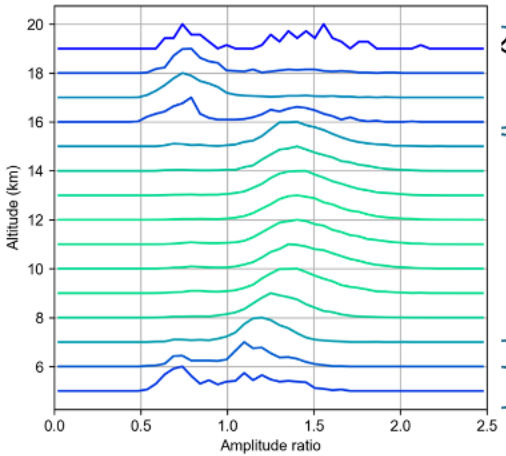
Look at amplitude ratio of second pulse to first pulse

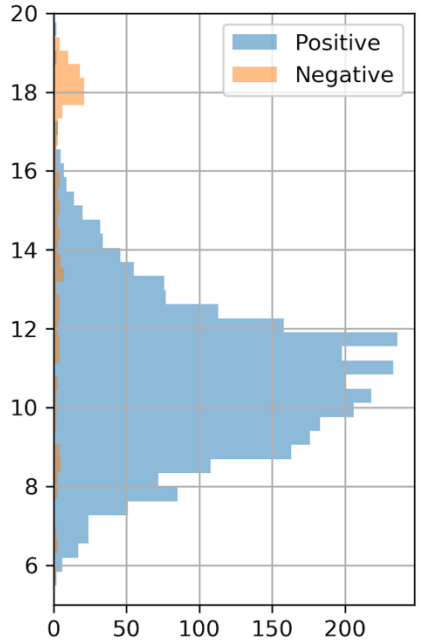
- Land vs. sea suggests reflectivity is important
- Reflectivity can only make the second pulse weaker, not stronger
- Look at only TIPPs over ocean (reflectivity ~= 1)
- Automatic processing allows us to look at 70,000+ TIPPs and get altitude distributions



[Pailoor et al., 2025, JGR https://doi.org/10.1029/2025JD043403]

Altitude distribution suggests beaming based on charge movement direction (NBE polarity)





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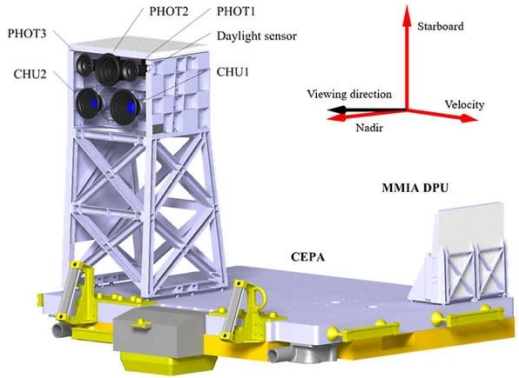
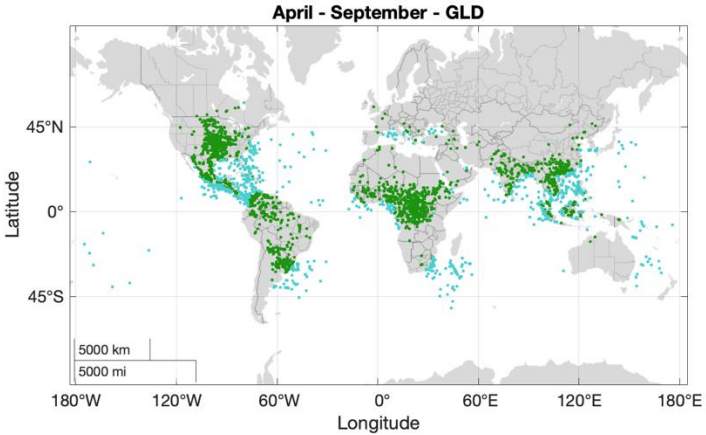
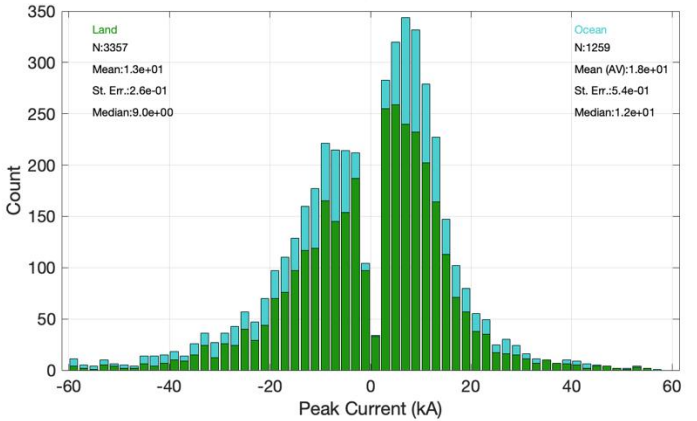
RFS detections correlated with ASIM optical detections

Atmosphere-Space Interactions Monitor (ASIM)

- MMIA instrument aboard the ISS at 400 km
- 3 photometer channels – 100 kHz sampling
  - 337 nm (blue)
  - 777 nm (red)
  - ~300 nm (UV)



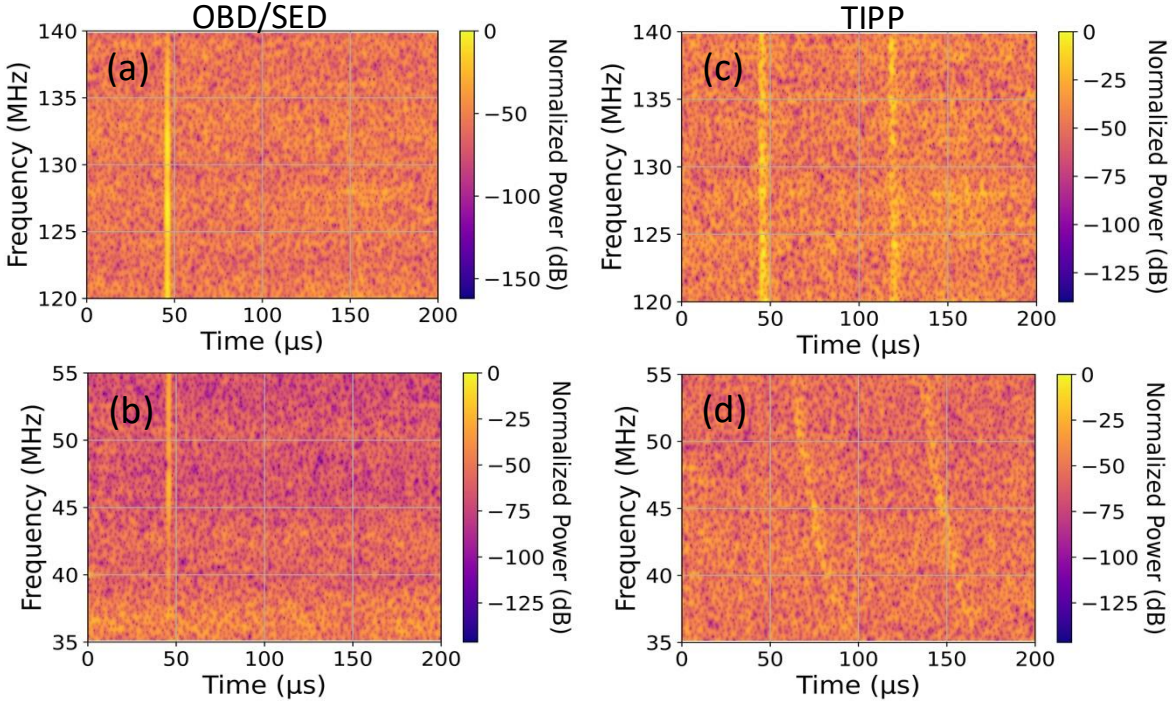




- Map and plot show distributions of GLD360 matched with ASIM.
- 90 RFS TIPPs have been geolocated by GLD360 and detected by ASIM.
- Most events were isolated blues, but some of the events had both blue and red emissions reported by ASIM.
- The peak currents of these events were both negative and positive polarity.

This will be presented in detail at AGU 2025 by Liane Tarnecki

Spacecraft Environment Discharges (SED)



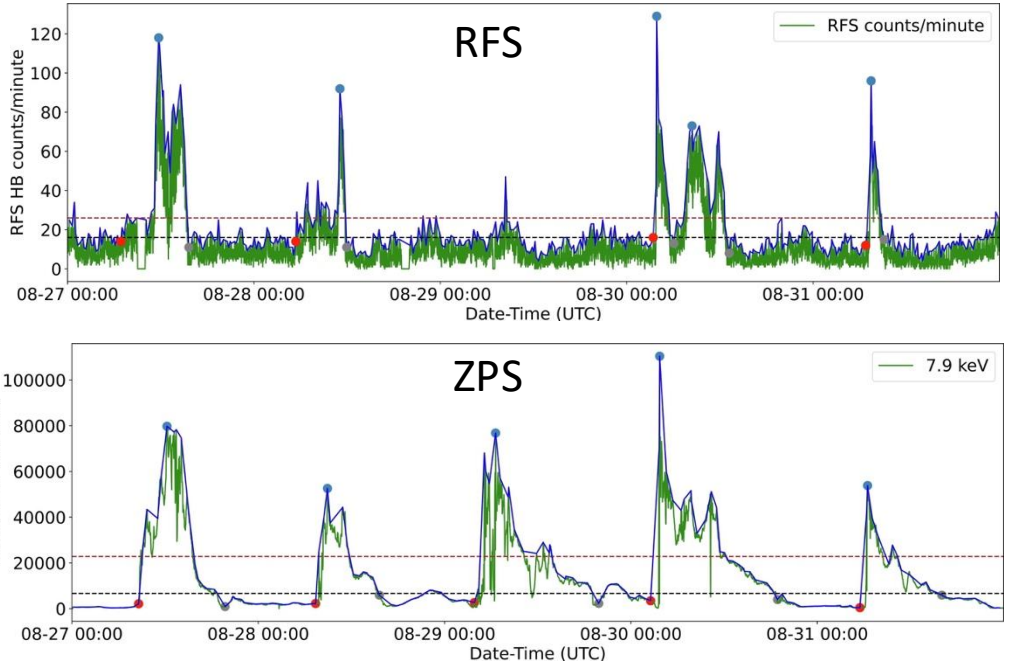
SED versus TIPP

- SEDs: impulsive, non-dispersed electric field signatures which often saturate the electric field measurement.
- Their non-dispersed nature suggests that they do not transit the ionosphere and are likely signatures of electrostatic discharges at/near the STP-Sat6.

[Nag et al., 2025, AISR, https://doi.org/10.1016/j.asr.2025.07.026]

Spacecraft Environment Discharges (SEDs)

- SEDs often occur in temporal clusters, with RFS count rates > 10 counts/minute and occasionally > 100 counts/minute.
- A Z-Plasma Spectrometer (ZPS) is also on STP-Sat 6, measuring electron and ion flux
- ZPS-Lo electron flux in time is shown to the right.



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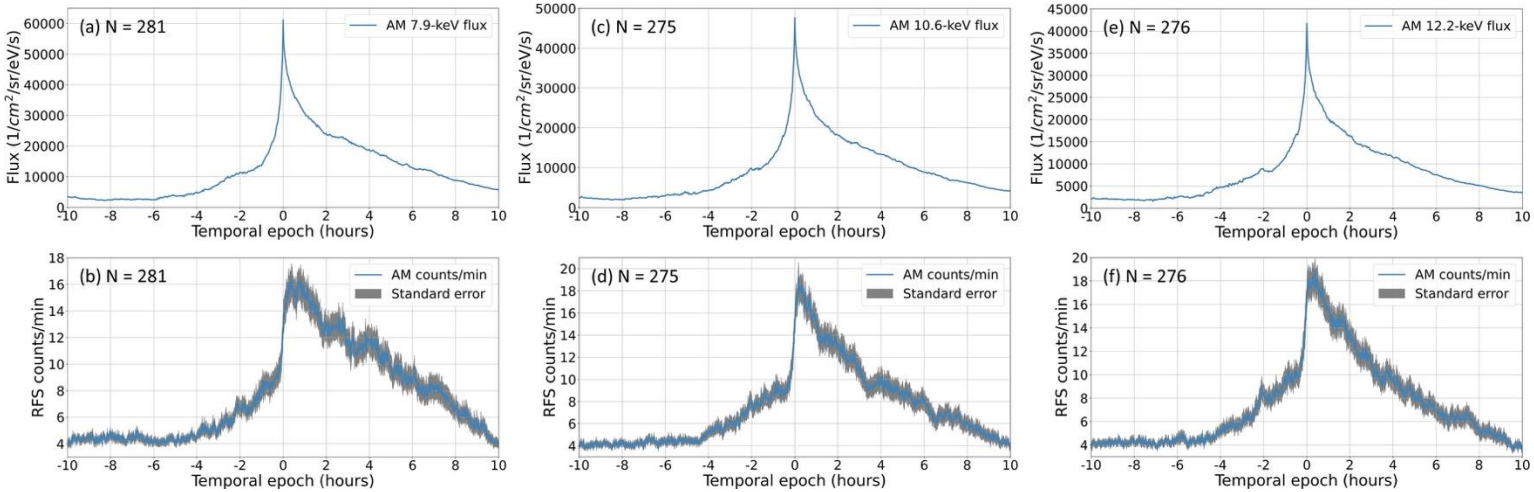
Understanding spacecraft environment discharges via RFS-SABRS analysis



Superposed epochs of electron flux at 7.9, 10.6, and 12.2 keV energies: ZPS flux peak occurs at the center of a 20-hour time-window.

RFS event counts/minute for the same temporal epochs; the gray shaded regions indicates the standard error.

- Peaks in SED count rates were time-correlated with peaks in electron flux. Electron flux peaks lead the SED count rate peaks by 24–45 min for the 7.9–12.2 keV energies.
- Suggests that electrons at this relatively low-energy range likely resulted in ramping up of the charging of the spacecraft leading to periods of high occurrence rates of discharges in and around the spacecraft.

[Nag et al., 2025, AISR, https://doi.org/10.1016/j.asr.2025.07.026]

Work in progress

- RFS data release: Waveforms, times, RFS locations for lightning events and SEDs
- Machine-learning based event-type classification (TIPP, CG, SED)
- Comparisons with BLUEs (337 nm) – ASIM recently re-pointed to nadir
- Collaboration with ground-based campaigns (Columbia LMA)

References

- Lay, E.H., Romero, L., Peterson, M. et al. (2024), Radio Frequency Sensor: Very High Frequency Radio Frequency Lightning Detection in Geostationary Orbit, Radio Science, https://doi:10.1029/2023RS007931
- Nag A., **Lay, E. H.**, Larsen, B.A., Mark, M.D, Fernandes, P.A., Attanasio A.R., (2025) Radio Frequency Transients Correlated with Electron Flux Measured On-Board the STP-Sat6, Advances in Space Research, ISSN 0273-1177, https://doi.org/10.1016/j.asr.2025.07.026
- Pailoor, N. A., Lay, E. H., Nag, A., & Anderson, T. S. (2025). Statistical analysis of trans-ionospheric pulse pairs and inferences on their characteristics. *J. of Geophys. Res.: Atmos., 130*, e2025JD043403. https://doi.org/10.1029/2025JD043403