# Lightning Geolocation and Classification During the RELAMPAGO Field Campaign

Andre Lucas Antunes de Sa[1], Robert Marshall[1], Wiebke Deierling[2], and Austin Sousa[1]

[1]University of Colorado at Boulder
[2]National Center for Atmospheric Research

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**Abstract**

Severe weather forecasting is an important tool for mitigating damages brought by intense lightning, large hail, heavy precipitation, strong winds, or tornadoes during thunderstorms, yet the reliability of such forecasts suffers from our limited understanding of the severe weather generative processes inside thunderclouds. With an increasing knowledge of the occurrence context of distinct types of lightning within storms, lightning remote sensing may elucidate the kinematic and microphysical environment where severe weather initiates. In particular, distinct energetic intra-cloud (IC) lightning discharges, compact intra-cloud lightning discharges [CID; e.g., Nag and Rakov, 2010] and energetic intra-cloud pulses [EIP; e.g., Lyu et al., 2015], have been shown to have different occurrence contexts, making them strong candidates for thunderstorm remote sensing research. In this study, observations from the RELAMPAGO field campaign in Argentina (November 1 to December 12th 2018) are used to determine lightning flash rates and the prevalence of different energetic lightning types in RELAMPAGO storms, enabling further research on the link between lightning activity and severe weather production inside thunderstorms.Lightning events during RELAMPAGO were observed by a deployed array of four Low-Frequency (LF, ˜1-400 kHz) radio receivers. Using time of arrival, magnetic direction finding, and peak amplitude for each observed event at different stations, lightning source locations are estimated using a statistical least squares filter, along with clock and site errors associated with the receivers. Return stroke peak current for each event is also estimated in the filter, using an atmospheric attenuation observation model. The energetic lightning events in the campaign are then classified automatically between cloud-to-ground (CG), IC, CID or EIP, following an improved parametrization scheme originally proposed by Lyu et al. [2015]. In this paper we present the geolocation and classification of RELAMPAGO lightning events, and we also provide an analysis of lightning flash rates during the campaign. A few individual thunderstorm case studies are also discussed, which are augmented by other meteorological data from dual-polarimetric radar, hailpads, and other sources.

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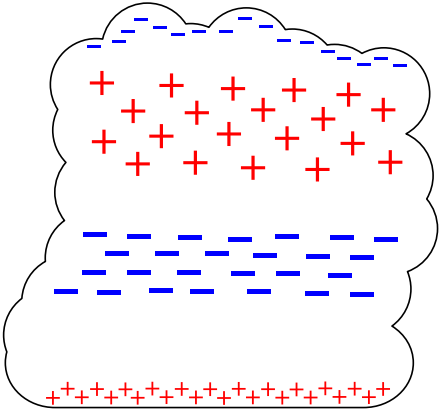
Department of Aerospace Engineering Sciences

University of Colorado Boulder

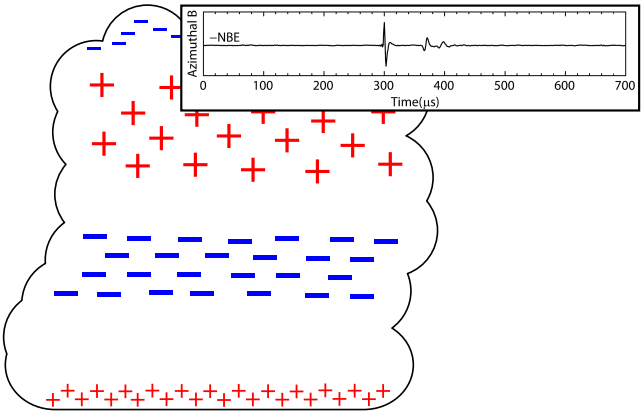
DECEMBER 9, 2019

# Energetic ICs



# Energetic ICs

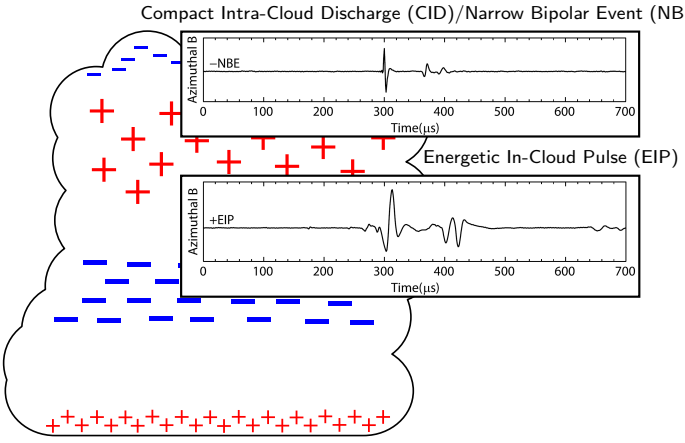
Compact Intra-Cloud Discharge (CID)/Narrow Bipolar Event (NBE)




Adapted from Lyu et al. [2015]

- Energetic IC Lightning:
  - CIDs – Narrow, Isolated (Physically & Temporally)

## Energetic ICs

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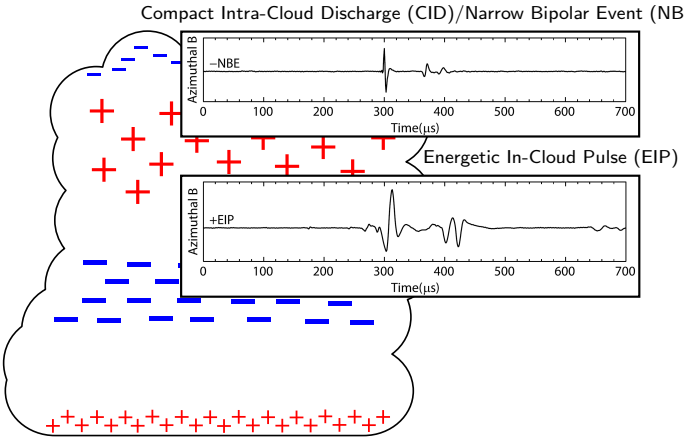


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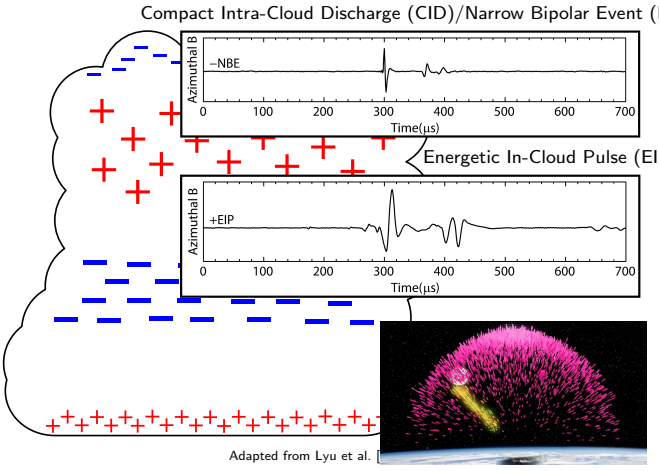
  - EIPs – Suggested by Cummer et al. [2013]
- Lyu et al. [2015]:
  - Studied Occurrence Context
  - Suggested Parametrization

# Energetic ICs




Adapted from Lyu et al. [

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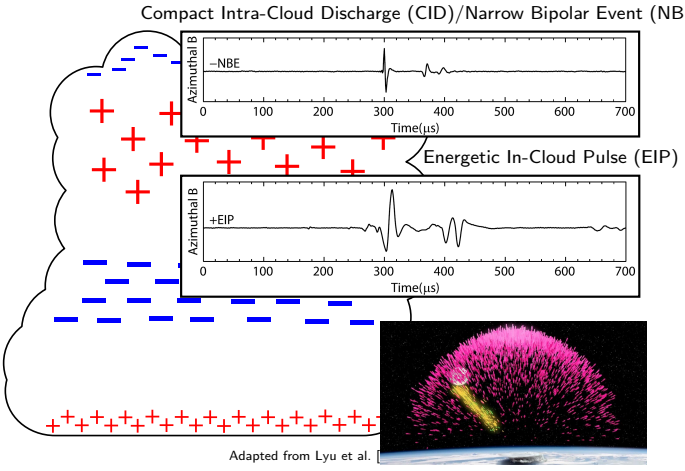
  - EIPs – Suggested by Cummer et al. [2013]
- Lyu et al. [2015]:
  - Studied Occurrence Context
  - Suggested Parametrization
- TGF Connection to EIPs:
  - Lyu et al. [2015, 2016, 2018] Lyu and Cummer [2018]

# Energetic ICs

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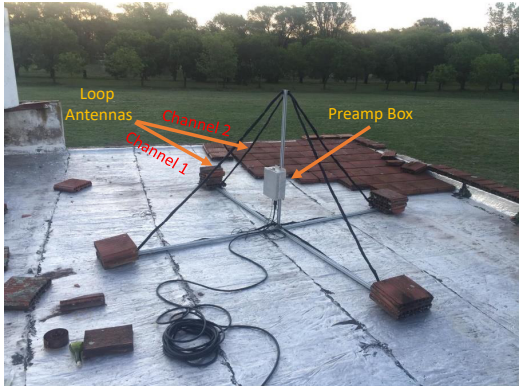
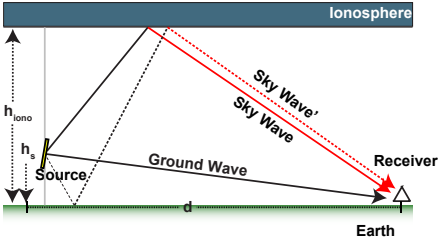
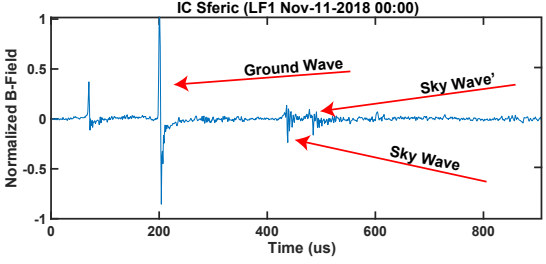
  - Lyu et al. [2015, 2016, 2018] Lyu and Cummer [2018]

Characterize the Prevalence And Occurrence Context of Energetic ICs

# Instrument


Loop
Antennas
Channel 2
Channel 1
Preamp Box


Ionosphere
$h_{iono}$
$h_s$
Source
Sky Wave'
Sky Wave
Ground Wave
Receiver
d
Earth


IC Sferic (LF1 Nov-11-2018 00:00)
Normalized B-Field
1
0.5
0
-0.5
-1
0
200
400
600
800
Time (us)
Ground Wave
Sky Wave'
Sky Wave

# RELAMPAGO

Dean Funes LF1

Manfredi LF2

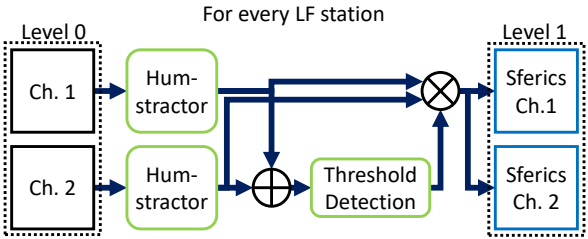


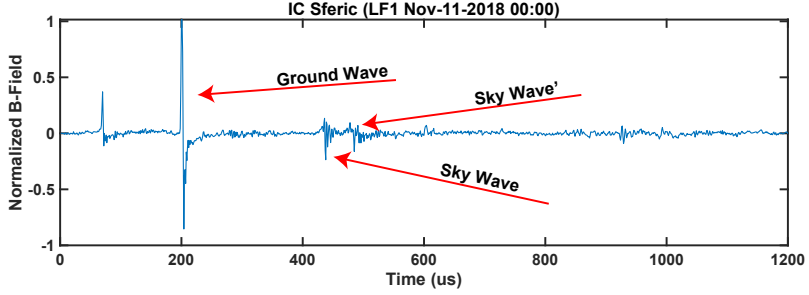

Las Catitas LF 4



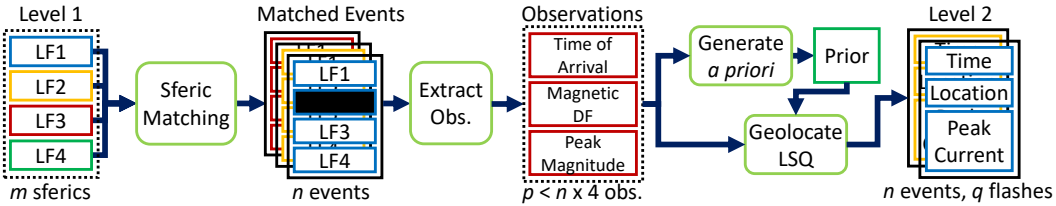
Realico LF3

# LF Level 1 Data Processing

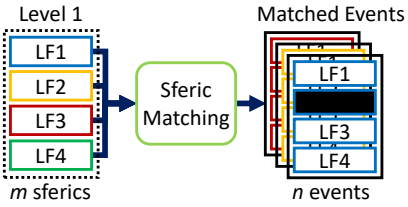


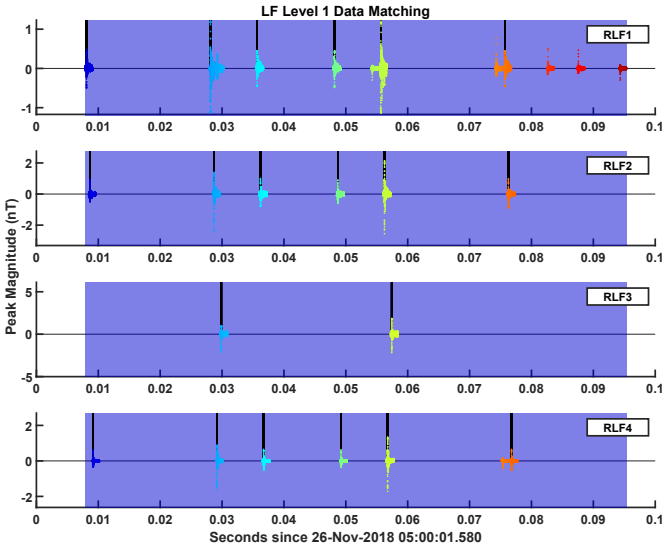



## LF Level 2 Data Processing



# LF Level 2 Data Processing



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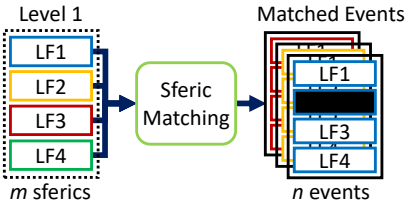
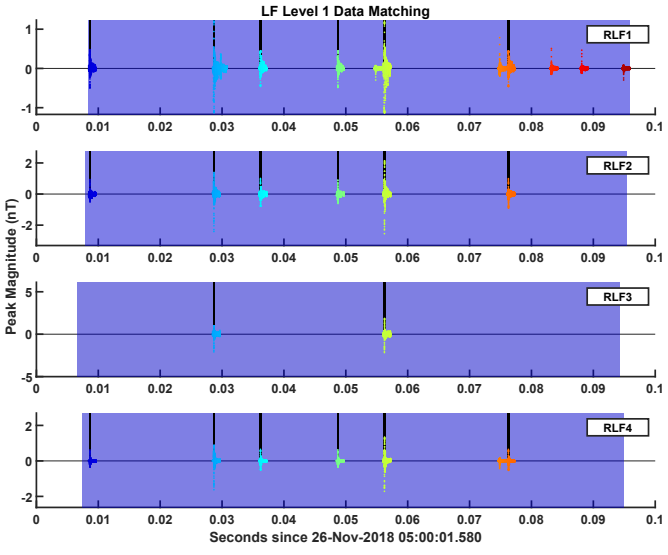
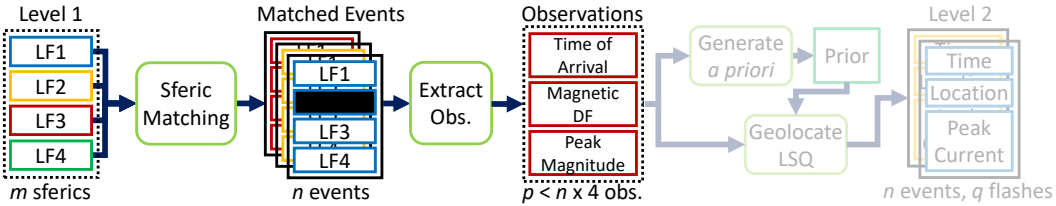


# LF Level 2 Data Processing



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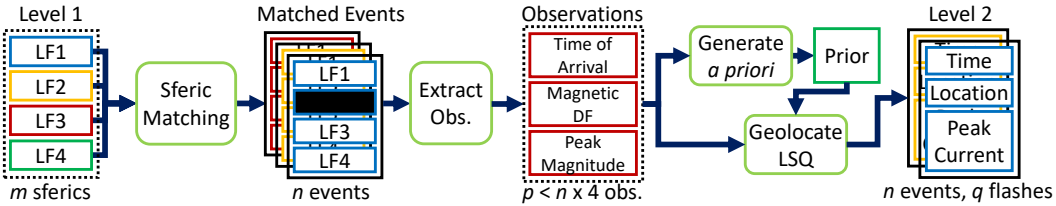

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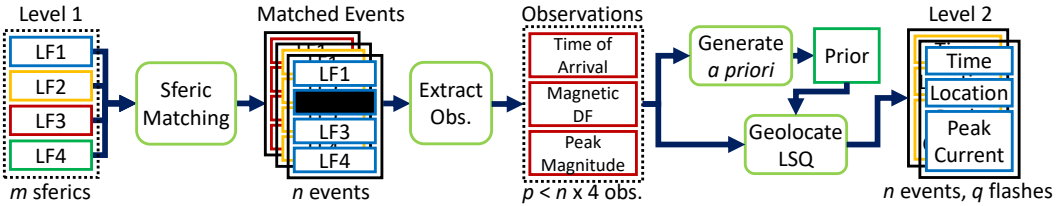

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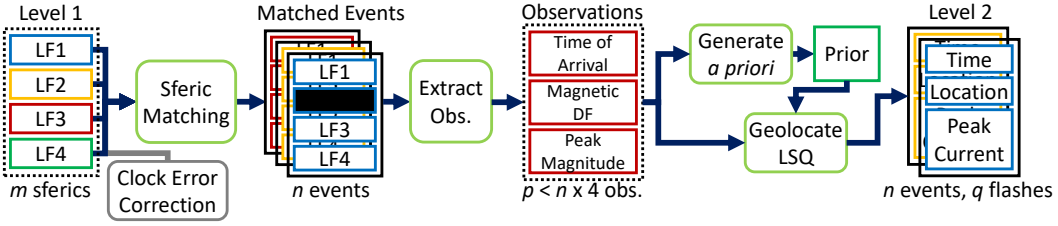


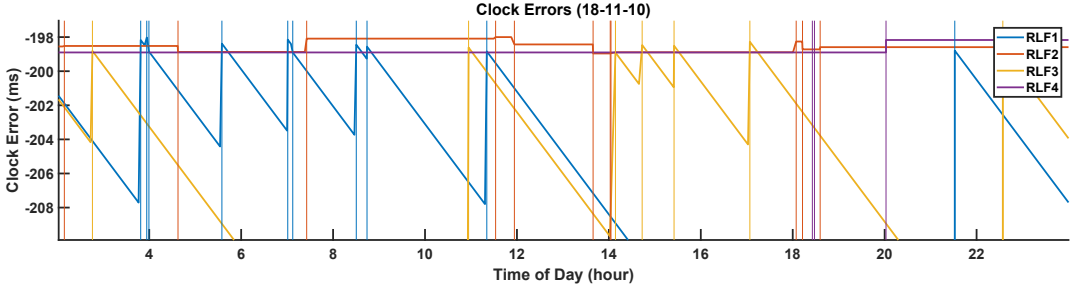

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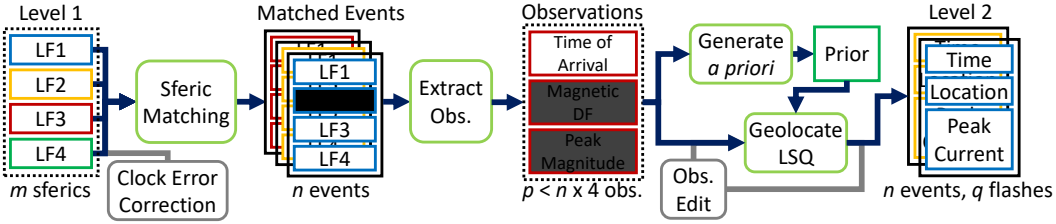

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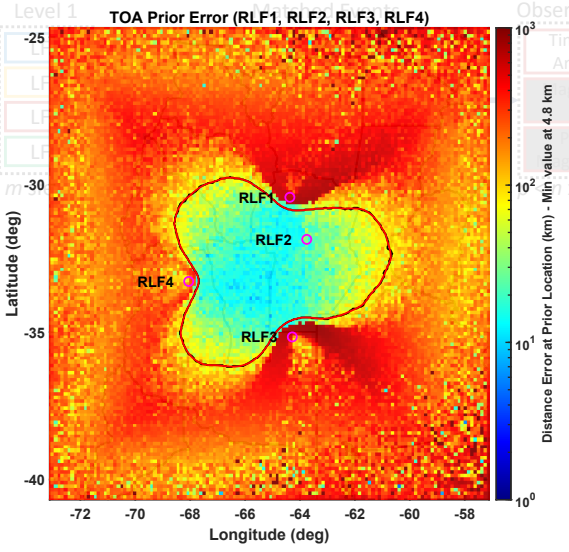
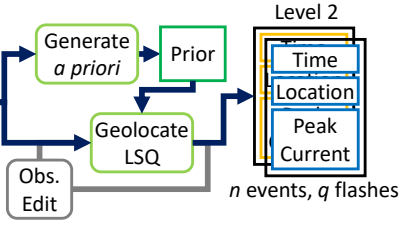
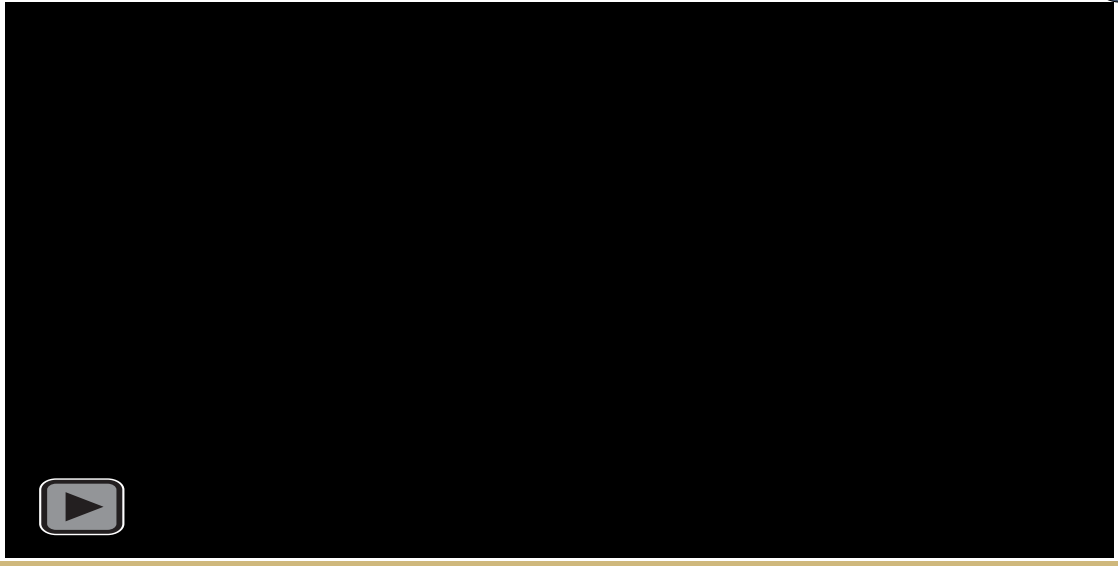
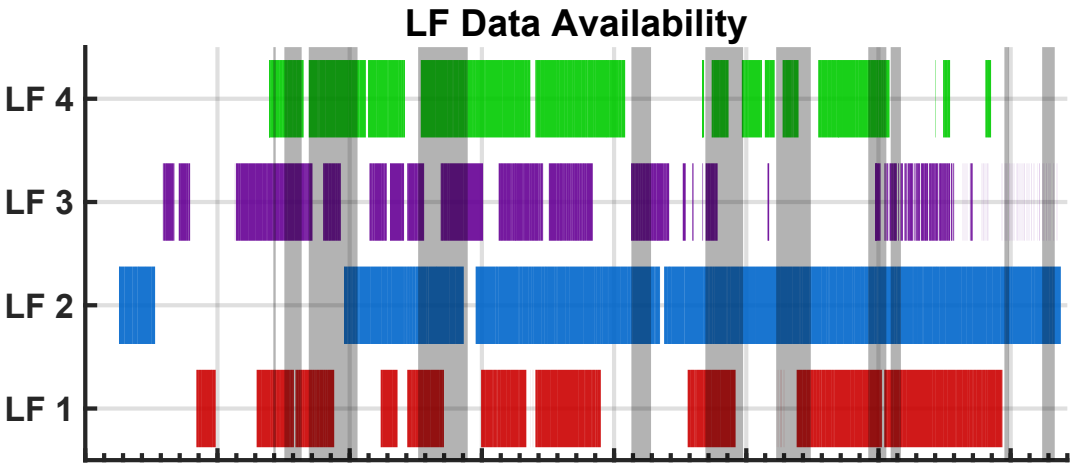


## Geolocated Flashes (Nov. 10 2018 17-24 UTC)



## RELAMPAGO - LF Data Availability



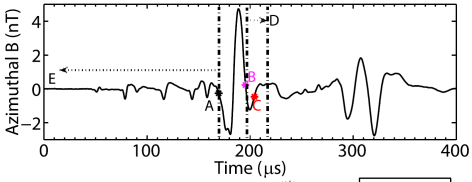

*Data gaps during storms were caused by power outages

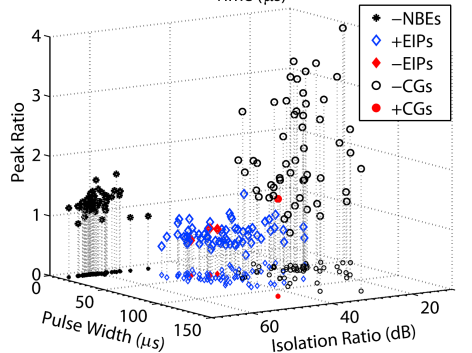
## Energetic IC Classification

**Parametrization (Lyu et al. [1])**

- Pulse Width (A-C)
- Peak Ratio (Initial Peak to Main Peak)
- Isolation Ratio:

$$10 \times \log_{10} \left[ \frac{\frac{1}{\mathrm{B-A}} \left( \sum_A^B B_i^2 \right)}{\frac{1}{\mathrm{A-E}} \left( \sum_E^A B_j^2 \right)} + \frac{\frac{1}{\mathrm{B-A}} \left( \sum_A^B B_i^2 \right)}{\frac{1}{\mathrm{D-B}} \left( \sum_B^D B_j^2 \right)} \right]$$

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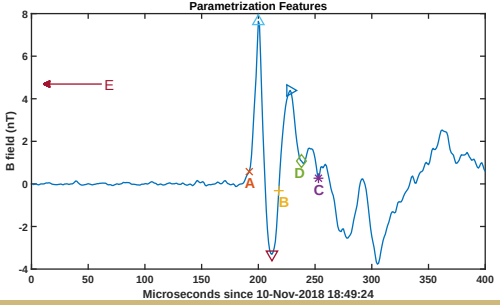
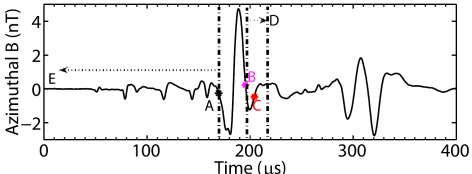
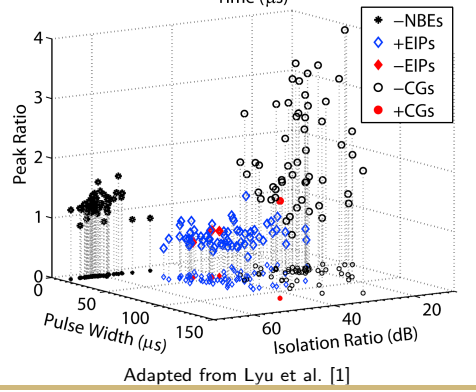



Adapted from Lyu et al. [1]

## Case Study - Energetic IC Preliminary Classification (11/10/2018)

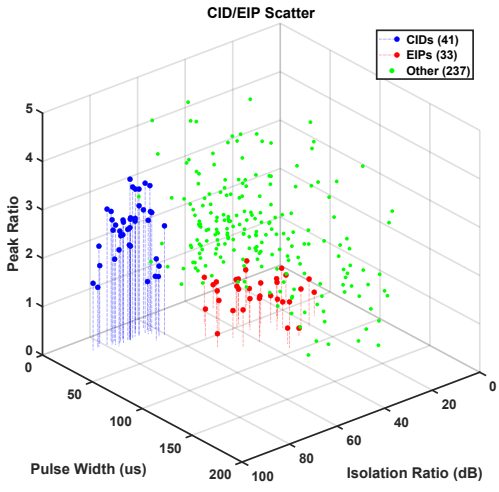
### Preliminary Classification

- Selected Peak Current >80 kA

| Criteria | Width | Pk. Ratio | Iso. Ratio |
|---|---|---|---|
| CID | <35 µs | NA | >60 dB |
| EIP | >40 µs | <1.0 | NA |

- EIP-CG Classification Challenges

| Mean | Width | Pk. Ratio | Iso. Ratio |
|---|---|---|---|
| CID | 18 µs | 2.2 | 70 dB |
| EIP | 57 µs | 0.7 | 34 dB |



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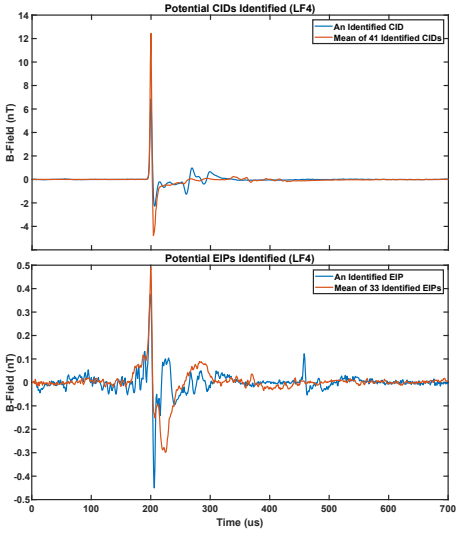

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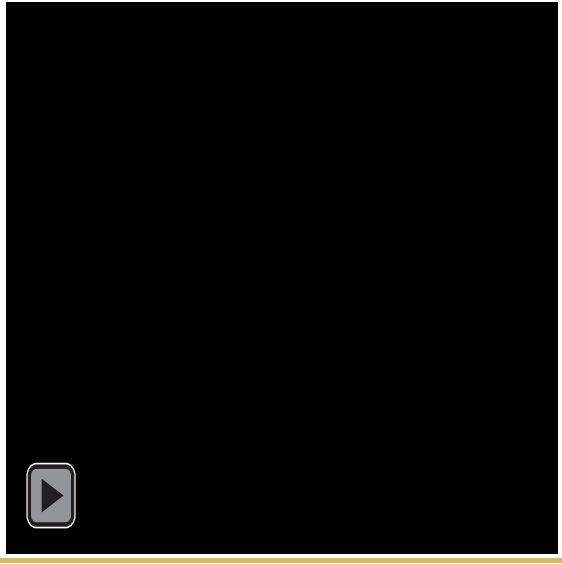


# Conclusion

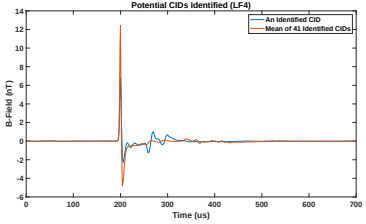
## Summary

- Completed RELAMPAGO Geolocation of LF Strokes and Flashes
- Studying Prevalence and Occurrence Context (Next) of Energetic ICs
- Using Data from Multiple Instruments during RELAMPAGO Campaign
- Developed Preliminary Energetic IC Classification Framework (11/10/18 18-24 UTC: 22k Geolocated Flashes, 135k Geolocated Events, 311 Energetic (>80 kA), 41 CIDs and 33 EIPs Identified)

## Next Steps

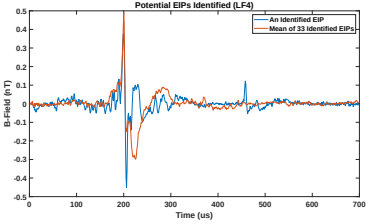
- Study CIDs/EIPs in the Meteorological Context of RELAMPAGO Storms

## Thank You!




# Questions?

Q&A Session
on
12/10/2020 05:45 PST




This work was supported by National Science Foundation grant #1661726 to the University of Colorado Boulder, and by the NASA Earth and Space Science Fellowship grant #80NSSC17K0392.

**Acknowledgments:**

- Larry Carey, Phillip Bitzer, Jeff Burchfield, Bruno Medina (UAH)
- Timothy Lang (NASA)
- Eldo Avila, Rodolfo Pereyra, Analia Pedernera (Universidad Nacional de Cońdoba)
- NOAA, Earth Networks Total Lightning Network [7]

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[1] Fanchao Lyu, Steven A. Cummer, and Lindsay McTague. Insights into high peak current in-cloud lightning events during thunderstorms. *Geophysical Research Letters*, 42(16): 6836–6843, 2015. doi: 10.1002/2015gl065047.

[2] Steven A. Cummer, Walter A. Lyons, and Mark A. Stanley. Three years of lightning impulse charge moment change measurements in the united states. *Journal of Geophysical Research: Atmospheres*, 118(11):5176–5189, jun 2013. doi: 10.1002/jgrd.50442.

[3] Fanchao Lyu, Steven A. Cummer, Michael Briggs, Martino Marisaldi, Richard J. Blakeslee, Eric Bruning, Jennifer G. Wilson, William Rison, Paul Krehbiel, Gaopeng Lu, Eric Cramer, Gerard Fitzpatrick, Bagrat Mailyan, Sheila McBreen, Oliver J. Roberts, and Matthew Stanbro. Ground detection of terrestrial gamma ray flashes from distant radio signals. *Geophysical Research Letters*, 43(16):8728–8734, 2016. doi: 10.1002/2016gl070154.

[4] Fanchao Lyu, Steven A. Cummer, Paul R. Krehbiel, William Rison, Michael S. Briggs, Eric Cramer, Oliver Roberts, and Matthew Stanbro. Very high frequency radio emissions associated with the production of terrestrial gamma-ray flashes. *Geophysical Research Letters*, 45(4):2097–2105, feb 2018. doi: 10.1002/2018gl077102.

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[5] Fanchao Lyu and Steven A. Cummer. Energetic radio emissions and possible terrestrial gamma-ray flashes associated with downward propagating negative leaders. *Geophysical Research Letters*, 45(19):10,764–10,771, oct 2018. doi: 10.1029/2018gl079424.

[6] Eric C. Bruning and Donald R. MacGorman. Theory and observations of controls on lightning flash size spectra. *Journal of the Atmospheric Sciences*, 70(12):4012–4029, dec 2013. doi: 10.1175/jas-d-12-0289.1.

[7] Stan Heckman. EntIn status update. In *XV International Conference on Atmospheric Electricity*, pages 15–20, 2014.