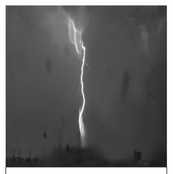
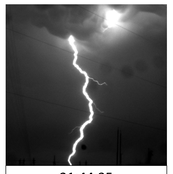
SAND2025-00181C

# Development of a Classification Method for Geostationary Lightning Mapper (GLM) Data Using Simultaneous Lightning Observations from Ground and Geostationary Orbit

Beatrice E. Shea[1], Thom R. Edwards[2], Lydia Wermer[2], Eric Bruning[3]

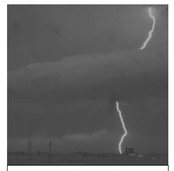
(1)U.S. Air Force Academy, (2) Sandia National Laboratories, (3) Texas Tech University


21:42:37

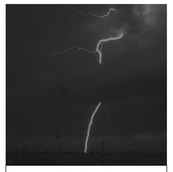

21:44:35

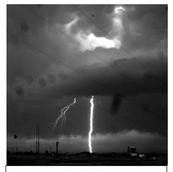

21:45:01


23:01:15


23:03:17


23:03:27


23:05:41


23:06:36

## Introduction

To better understand the spectral content of lightning, and to support future validation efforts for space-based lightning sensors, Sandia National Laboratories (SNL) has deployed four radiometers and a contextual camera at Texas Tech University's (TTU) field site to capture optical spectral data alongside the other established sensors at TTU. Based on their timestamps, we matched 8 of 13 signals collected on May 28, 2024, to group data from the Geostationary Lightning Mapper (GLM) sensors hosted on GOES 16 and 18 satellites. Based on the contextual camera imagery, these events are primarily Cloud to Ground (CG) strokes. Using this feature of the data, one goal in this project is to develop a classification method for GLM data to distinguish between CG and In Cloud (IC) flashes.

## Data

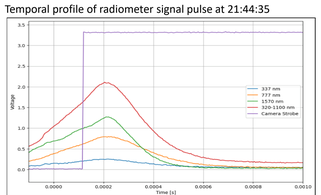
- Sandia Radiometers – ground based optical sensors that measure natural lightning at multiple wavelengths collocated with other instrumentation.
- Date of the dataset is 05/28/2024
- Faulty trigger timestamps are excluded from the analysis
- Time difference is calculated: Time Radiometer – Time of GLM Candidate
- Inter-Range Instrumentation Group (IRIG) is a time code format used for synchronizing and time-stamping measurements
  - IRIG time is used as radiometer time
- Located at TTU in Lubbock, TX
  - Field of view is 330° off North within 10° each side

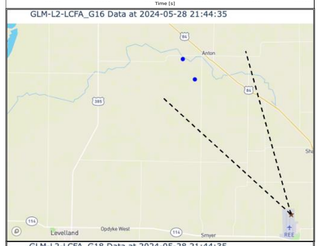
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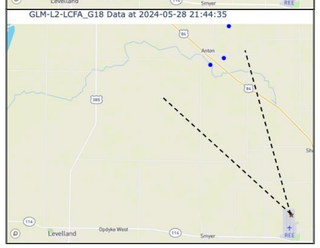
- GLM – imager that maps the extent of cloud illumination and detects total lightning: in cloud, cloud-to-cloud, and cloud-to-ground
  - GLM data are from GLM16 and GLM18
  - TTU is in the stereo region for GLM, allowing both GLM16 and GLM18 to view the area surrounding TTU and the deployed radiometer.
  - Group level data – set of adjacent GLM pixel events during one 2ms frame combined to a centralized location
- Each radiometer timestamp is checked ten seconds prior and after to ensure potential GLM matches

Radiometer [33.61,-102.04] ★
GLM Group Energy ⬬

Temporal profile of radiometer signal pulse at 21:44:35




GLM16 and GLM 18 plots of GLM group energy relative to radiometer location

## Methodology

- Filtered out faulty triggers
- Identified likely matches between the radiometer data and GLM
- Listed top four GLM candidates based on smallest time difference
- Calculated distribution of GLM selected candidates
- Categorized GLM matches based on proposed detection and event classification
- Verified accuracy of potential matches by calculating candidate distances, comparing corresponding event images, and analyzing radiometer signal plots
  - Distances are calculated using the Haversine Formula
- Continued process for June 01, June 09, August 15, and August 17 Data sets

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- Identified relationship between uncalibrated 777nm and 337nm signal peaks in CG and IC events
- Developed a Random Forests Model (RFM) in which uses 777nm and 337nm peak relation and manual event tagging of contextual camera to classify peaks as CG or IC
- Validated RFM CG and IC classifications were done by comparing to radiometer event images for May 28, June 01, June 09, August 15, and August 17
- Compared GLM candidates to RFM outputs to identify the best match

## Definitions

- GLM Candidate (C) – A single group event that GLM has identified within the radiometer's FOV and 30km range that strongly aligns with radiometer signal and timing.
- Miss – Absence of GLM16 and GLM18 single group events that could be GLM candidates or a majority of GLM candidates with an absolute time difference greater than 0.5 seconds.
- Hit – GLM16 and GLM18 single group events that have at least one timing alignment with radiometer under an absolute time difference of 0.5 seconds and is within 30km of the radiometer.
  - Stroke – Absolute time difference of 0.002 or less seconds
  - Flash – Absolute time difference of 0.1 or less seconds
  - Cell – Absolute time difference of 0.5 or less seconds

## References

Ringhausen, Jacquelyn, et al. "Classification of GLM Flashes Using Random Forests." *Earth and Space Science*, vol. 8, no. 11, 21 Oct. 2021, https://doi.org/10.1029/2021ea001861. Accessed 1 Jan. 2025.

Rudlosky, S. D., Goodman, S. J., Virts, K. S., & Bruning, E. C. (2019). Initial geostationary lightning mapper observations. Geophysical Research Letters, 46, 1097–1104. https://doi.org/10.1029/2018GL081052

## Current Results

Summarized tables of GLM16 and GLM18 time differences and applied definitions of the top 3 potential GLM candidate matches.

Table 1. Time Difference between Radiometer and GLM16 Top Candidates

| IRIG (HH:MM:SS.FFFF) | Δ Time C1 (sec) | Δ Time C2 (sec) | Δ Time C3 (sec) | C1 Distance (km) | Event Classification |
|---|---|---|---|---|---|
| 21:42:37.7030 | N/a | N/a | N/a | - | Miss |
| 21:44:35.7140 | -0.0004 | -0.2392 | -0.3384 | 26.187 | Stroke |
| 21:45:01.4788 | 1.0504 | 1.2651 | 1.2693 | 61.905 | Miss |
| 23:01:15.1332 | -0.1471 | -0.4138 | -0.6640 | 27.972 | Cell |
| 23:03:17.6267 | -0.4907 | -0.4987 | -0.5086 | 63.890 | Miss |
| 23:03:27.0316 | -0.0024 | -0.2469 | N/a | 24.190 | Stroke |
| 23:05:41.5914 | 1.1420 | 1.1916 | 1.5376 | 206.68 | Miss |
| 23:06:36.5286 | -0.0007 | -0.3146 | -0.3207 | 27.789 | Stroke |
| 23:07:54.0890 | -0.1720 | -0.1739 | -0.6290 | 29.618 | Cell |
| 23:18:26.3418 | -0.0009 | -0.0844 | -0.1085 | 29.432 | Stroke |
| 23:24:36.9451 | N/a | N/a | N/a | - | Miss |
| 23:27:50.8343 | 0.0080 | -0.0037 | -0.0060 | 29.720 | Flash |
| 23:33:10.3009 | -0.0526 | -0.1479 | -0.1598 | 05.874 | Flash |

Table 2. Time Difference between Radiometer and GLM18 Top Candidates

| IRIG (HH:MM:SS.FFFF) | Δ Time C1 (sec) | Δ Time C2 (sec) | Δ Time C3 (sec) | C1 Distance (km) | Event Classification |
|---|---|---|---|---|---|
| 21:42:37.7030 | N/a | N/a | N/a | - | Miss |
| 21:44:35.7140 | 0.0155 | -0.0004 | -0.2389 | 23.218 | Stroke |
| 21:45:01.4788 | 1.2754 | 1.2697 | 1.2674 | 54.219 | Miss |
| 23:01:15.1332 | -0.1460 | -0.1479 | -0.4142 | 24.801 | Cell |
| 23:03:17.6267 | -0.5231 | -0.6005 | -0.6760 | 52.753 | Miss |
| 23:03:27.0316 | -0.1218 | -0.2690 | -0.5731 | 25.757 | Cell |
| 23:05:41.5914 | N/a | N/a | N/a | - | Miss |
| 23:06:36.5286 | 0.0584 | -0.0014 | - | 24.021 | Flash |
| 23:07:54.0890 | -0.0755 | -0.0816 | -0.1731 | 25.776 | Flash |
| 23:18:26.3418 | -0.0005 | -0.0024 | -0.0860 | 26.991 | Stroke |
| 23:24:36.9451 | -1.0231 | -1.0448 | - | 44.001 | Miss |
| 23:27:50.8343 | 0.0069 | -0.0048 | -0.1112 | 26.236 | Flash |
| 23:33:10.3009 | -0.5008 | N/a | N/a | 09.713 | Cell |

Summarized table that compares GLM16 and GLM18 event candidate classifications and calculations

Table 3. Summary of GLM16 and GLM18 Differences

| IRIG (HH:MM:SS.FFFF) | GLM16 Proposed Detection | GLM18 Proposed Detection | GLM16 Distance (km) | GLM 18 Distance (km) | GLM16 Event Classification | GLM18 Event Classification |
|---|---|---|---|---|---|---|
| 21:42:37.7030 | Miss | Miss | - | - | Miss | Miss |
| 21:44:35.7140 | Hit | Hit | 26.187 | 23.218 | Stroke | Stroke |
| 21:45:01.4788 | Miss | Miss | 61.905 | 54.219 | Miss | Miss |
| 23:01:15.1332 | Hit | Hit | 27.972 | 24.801 | Cell | Cell |
| 23:03:17.6267 | Miss | Miss | 63.890 | 52.753 | Miss | Miss |
| 23:03:27.0316 | Hit | Hit | 24.190 | 25.757 | Stroke | Cell |
| 23:05:41.5914 | Miss | Miss | 206.68 | - | Miss | Miss |
| 23:06:36.5286 | Hit | Hit | 27.789 | 24.021 | Stroke | Flash |
| 23:07:54.0890 | Hit | Hit | 29.618 | 25.776 | Cell | Flash |
| 23:18:26.3418 | Hit | Hit | 29.432 | 26.991 | Stroke | Stroke |
| 23:24:36.9451 | Miss | Miss | - | 44.001 | Miss | Miss |
| 23:27:50.8343 | Hit | Hit | 29.720 | 26.236 | Flash | Flash |
| 23:33:10.3009 | Hit | Hit | 05.874 | 09.713 | Flash | Cell |

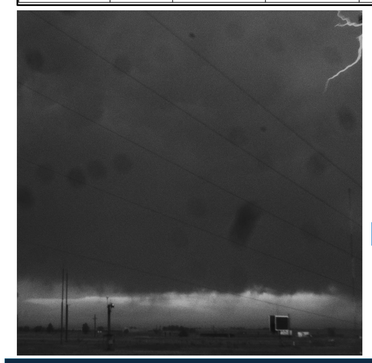
Table 4. Summary of Event Type Classification and Analysis to Determine GLM Best Match

| IRIG Time | Trigger Image | Image Classification | GLM Event Classification | RFM Event Classification | RFM Event Time Closest to IRIG | RFM Δ Time From IRIG (sec) | RFM Time that best matches a candidate | GLM Best Match |
|---|---|---|---|---|---|---|---|---|
| 21:42:37.7030 | Yes | CG | Miss | CG | 21:42:37.6949 | **0.0081** | 21:42:37.6949, | **None** |
| 21:44:35.7140 | Yes | CG | Stroke | CG | 21:44:35.6682 | **0.0458** | 21:44:35.7**52** | **(C1) GLM18** |
| 21:45:01.4788 | Yes | CG | Miss | CG | 21:45:01.4788 | **0.0000** | **IRIG Time** | **None** |
| 23:01:15.1332 | Yes | CG | Cell | CG | 23:01:15.0921 | **0.0411** | 23:01:14.9769 | **(C1) GLM16 (C2) GLM18** |
| 23:03:17.6267 | Yes | CG | Miss | CG | 23:03:17.6183 | **0.0084** | 23:03:17.6183 | **None** |
| 23:03:27.0316 | Yes | CG | Stroke | CG | 23:03:27.0228 | **0.0088** | 23:03:27.0228 | **None** |
| 23:05:41.5914 | Yes | CG | Miss | CG | 23:05:41.5796 | **0.0118** | 23:05:41.5796 | **None** |
| 23:06:36.5286 | Yes | CG | Stroke | CG | 23:06:36.5174 | **0.0112** | 23:06:36.5174 | **(C2) GLM18** |
| 23:07:54.0890 | Yes | CG | Cell | CG | 23:07:54.0837 | **0.0053** | 23:07:53.9090 | **(C2) GLM16 (C3) GLM18** |
| 23:18:26.3418 | Yes | CG | Stroke | CG | 23:18:26.3409 | **0.0009** | 23:18:26.3409 | **(C1) GLM16** |
| 23:24:36.9451 | Yes | CG | Miss | CG | 23:24:36.9448 | **0.0003** | **IRIG Time** | **None** |
| 23:27:50.8343 | Yes | CG | Flash | CG | 23:27:50.8256 | **0.0087** | 23:27:50.8256 | **(C1) GLM16** |
| 23:33:10.3009 | Yes | IC | Flash | IC | 23:33:10.3000 | **0.0009** | 23:33:10.2564 | **(C1) GLM16** |

- Corresponding group data suggests that the radiometer and GLM saw the same events for 8 out of 13 radiometer triggers on 05/28/2024.
- The absolute timing difference between radiometer and GLM is shown to be within 0.05 and 0.15 seconds.
- Analyzing the candidates of all timestamps indicates that radiometer and GLM timing matches best within 30km of the radiometer, thus a radiometer distance of detection that matches with GLM is between 5km and 30km.

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- Analyzing data from June 01 and June 09, 2024, revealed an unambiguous relationship between the uncalibrated 777nm and 337nm signals.
  - When 777>337 an event is CG.
  - When 337>777 an event is IC.
- We can use this to better understand when an event occurs relative to the radiometer's trigger. Narrow down a radiometer lightning event to its best GLM match.
- From this we classify events as IC or CG without having to rely on images.
- We can identify GLM16 and GLM18 detection capabilities relative to event timing and signal strength.



23:33:10

```
Time: 2024-05-28 23:33:10.256214970, Predicted Classification: Cloud-to-ground
Time: 2024-05-28 23:33:10.256464970, Predicted Classification: In-cloud
Time: 2024-05-28 23:33:10.256839969, Predicted Classification: Cloud-to-ground
Time: 2024-05-28 23:33:10.257039970, Predicted Classification: Cloud-to-ground
```

RFM Output: Example of IC classification of 337nm and 777nm optical signal peaks.

23:27:50

```
Time: 2024-05-28 23:27:50.823679980, Predicted Classification: In-cloud
Time: 2024-05-28 23:27:50.824689980, Predicted Classification: In-cloud
Time: 2024-05-28 23:27:50.825684980, Predicted Classification: Cloud-to-ground
Time: 2024-05-28 23:27:50.826689980, Predicted Classification: In-cloud
Time: 2024-05-28 23:27:50.827704980, Predicted Classification: In-cloud
```

RFM Output: Example of CG classification of 337nm and 777nm optical signal peaks.



## Conclusion

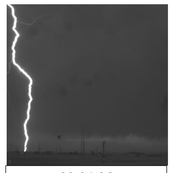
- Applying the RFM for the uncalibrated data collected on May 28, 2024, we draw the following preliminary conclusions:
  - Flash events best match with GLM16 with absolute timing differences as low as 0.05 and 0.008 seconds.
  - Cell events exhibit good alignment across GLM16 and GLM18 due to similar absolute timing differences.
  - Stroke events are less predictable and harder to attribute solely to GLM16 or GLM18 with 2 cases of GLM18 matches and one case of a GLM16 match.
  - Events labeled as misses, no GLM matches, may result from events falling outside the GLM detection threshold with absolute timing differences greater than 0.5 seconds or within 0 to 0.009 seconds.
- If we classify events by wavelength (777nm vs. 337nm) and their peaks occur on timescales misaligned with GLM's frame boundaries, detection becomes less reliable.
- The radiometer-classified events emphasize that GLM is better suited for IC detection due to its reliance on the 777nm signal. The radiometer's dual-channel (777nm + 337nm) capability provides a fuller picture, helping to fill gaps in GLM's detection.

## Future Research

- Intended objectives
  - Provide insights by classifying detected events using a pre-trained machine learning model.
  - Continue to narrow down and classify GLM matches and understand GLM misses.
- Calibrate radiometer data to relate the voltage measured on the detector to the energy of the photons hitting the detector.
- Continue to develop a random forests model to classify radiometer events to further understand proposed GLM threshold.
- Review timestamps that have radiometer pulse and image but no GLM match.
  - Determine if GLM has a lightning detection threshold that corresponds to events measured by the radiometers (i.e. cloud-to-ground events (CGs)).
- Compare Lightning Mapper Array (LMA) data and other TTU deployed instrumentation
- Process more radiometer data as it becomes available to ensure validity in results and conclusions.
- Develop a heuristic to identify IC or CGs from just looking at the light curves without the machine learning model.


23:07:54


23:18:26


23:24:36

Images for each timestamp of May 28, 2024, taken by the radiometer

*The Space Physics and Atmospheric Research Center and the Air Force Office of Scientific Research provided travel funding in support of this project.