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Comparison of Simultaneous Lightning Observation from Ground and Geostationary Orbit

Beatrice Shea (6771)
Lydia Wermer (6772)
Eric Bruning (Texas Tech University)
Thom Edwards (6771)

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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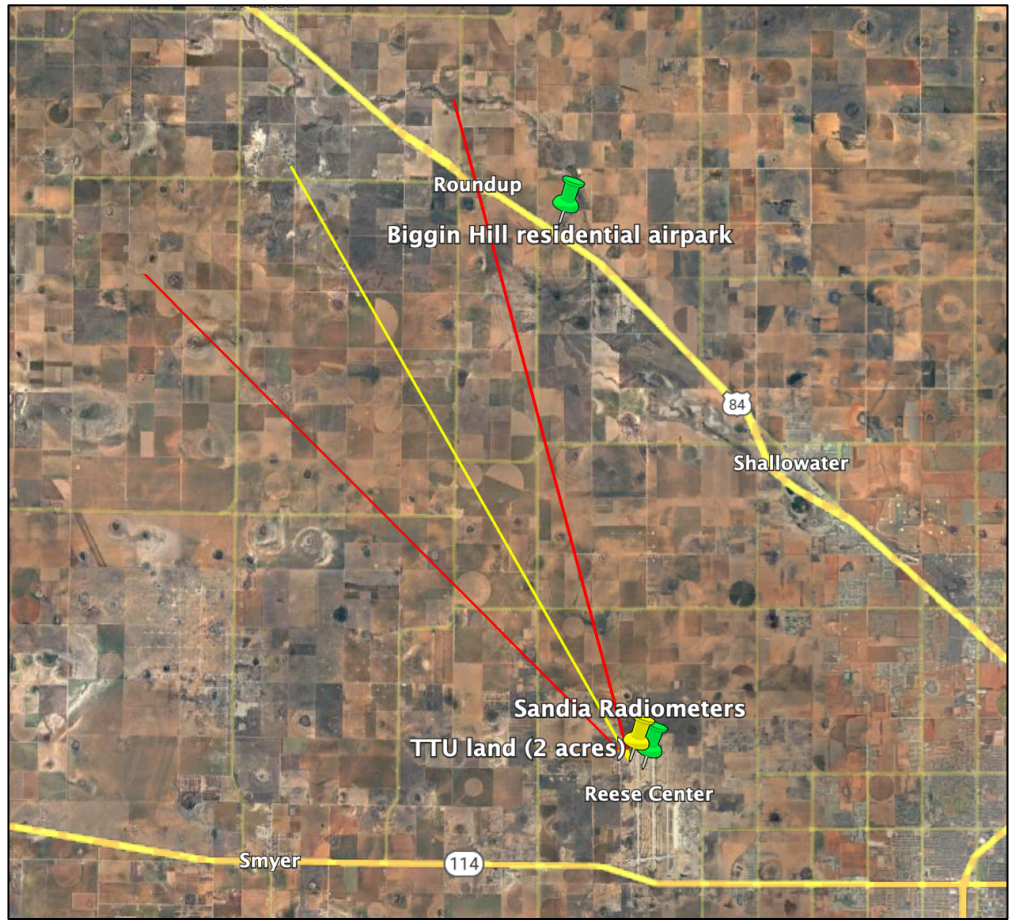
Background

- Lightning – rapid discharge of electrical energy in the atmosphere
  - Difficult phenomenon to capture thus it is important to observe from multiple viewpoints and techniques
  - Optical lightning observations provide insight to lightning physics and storm structure
  - Essential climate variable
- When new sensors and measurement techniques are deployed their detection performance requires evaluation

Introduction - Radiometer

- Sandia Radiometers – ground based optical sensors that measure natural lightning at multiple wavelengths collocated with other instrumentation.
  - Ground based optical lightning sensor
  - Channels include 337nm, 777nm, 1570nm, and Wide Band (320-1100nm)
- 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 Texas Tech University (TTU)
  - [33.61,-102.04]
  - Field of view is 330^{o} off North within 10^{o} each side
  - TTU is well instrumented with additional lightning measurement modalities, i.e. Lightning Mapping Array (LMA)



Introduction – Geostationary Lightning Mapper

- Geostationary Lightning Mapper (GLM) – imager that maps the extent of cloud illumination and detects total lightning: in cloud, cloud-to-cloud, and cloud-to-ground
  - Space based optical lightning sensor
  - TTU is in the stereo region for GLM, this means GLM16 and GLM18 can both see the region surrounding TTU

Significance of Analyzing Ground Based Lightning Sensors

- Current lightning detection methodologies only measure a subset of a complete lightning flash. Ground based optical measurements are notoriously difficult to capture, and can supplement both space based optical and ground based radio measurements.
  - It is unclear if ground sensors see the same events as space sensors because lightning channels within the cloud can span a large area
  - Complex lightning flashes could lead sensors to pick up different parts of the flash within the same storm
- Understanding the detection capabilities of ground and space based networks can help identify correlations that could improve optical lightning detection methods.

Project Overview

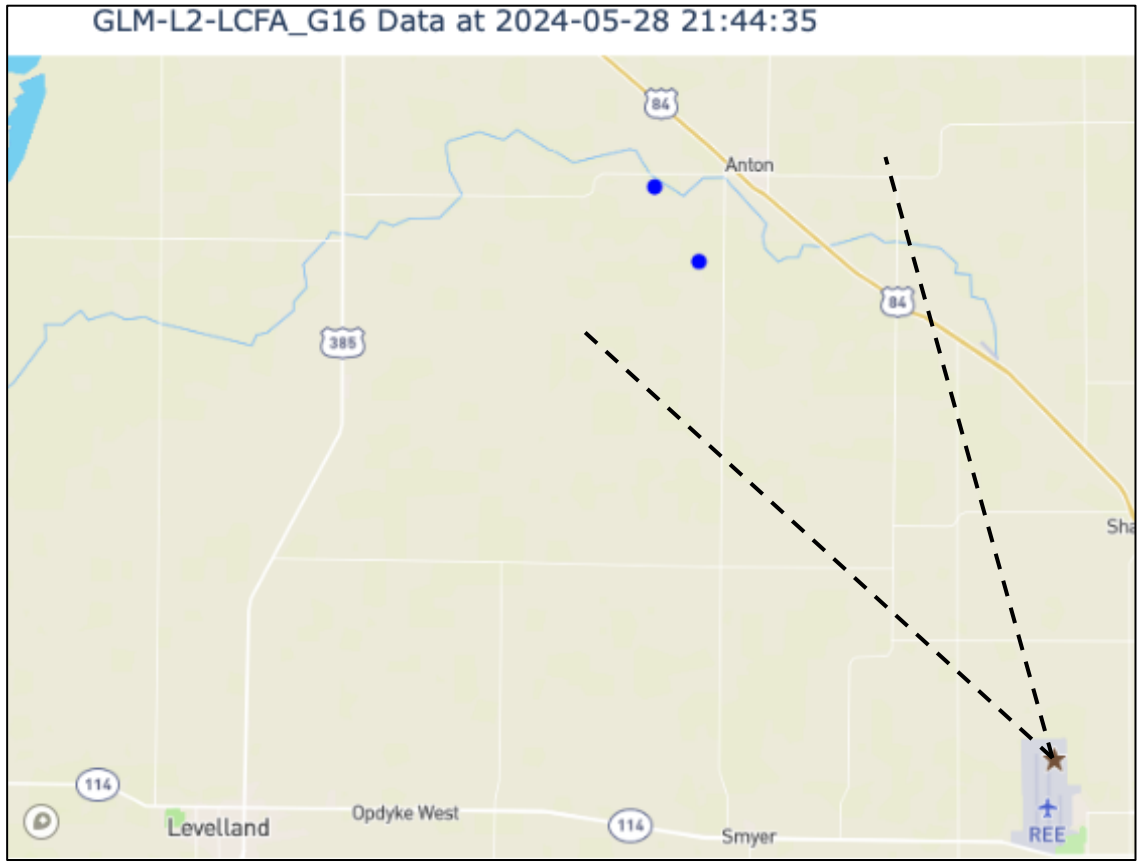
- Can we confirm the Sandia radiometers fielded at TTU and measurements from GLM correspond to the same events?
  - Analyze timing difference between radiometer measurements and GLM groups in the surrounding area.
  - Identify radiometer's maximum distance of detection

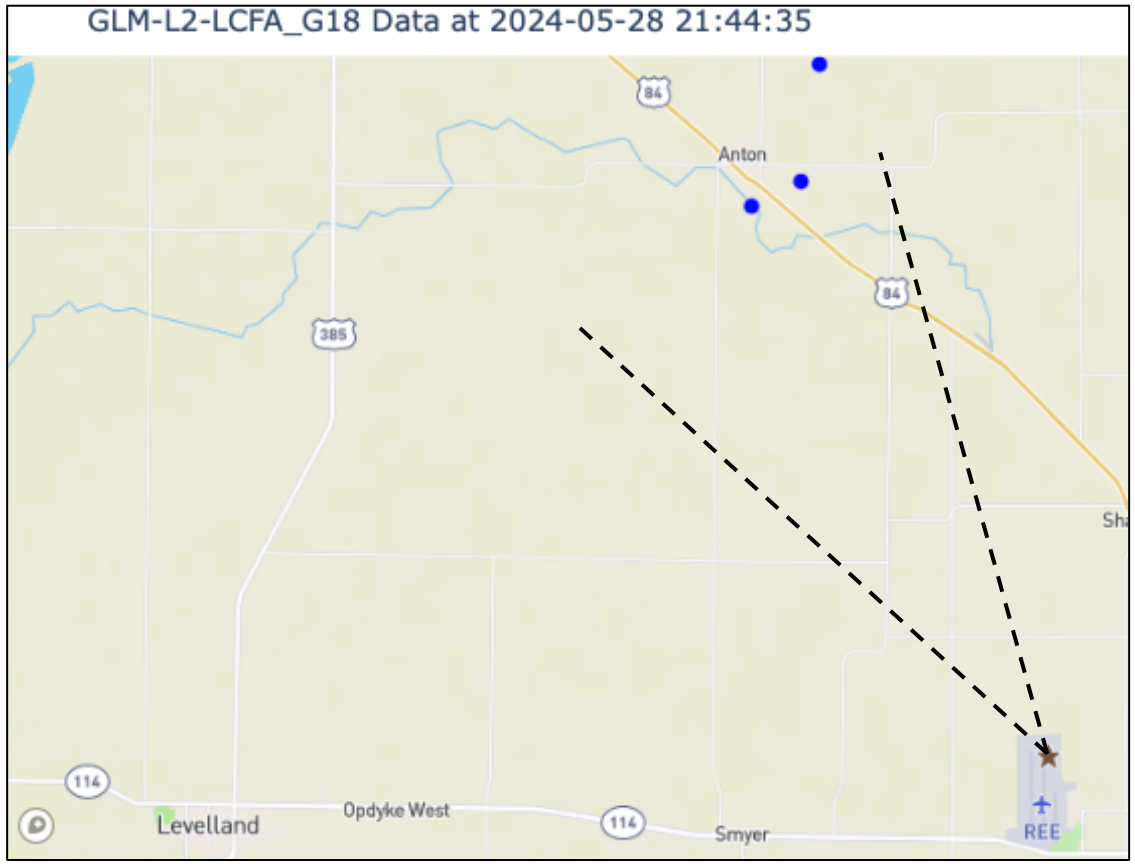
Overview of Data

- Radiometer data
  - 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
- GLM data are from GLM16 and GLM18
  - Group level data – set of adjacent GLM pixel events during one ~2 ms frame combined to a centralized location

Example: Comparison of Radiometer and GLM at 21:44:35

Radiometer: [33.61,-102.04]
GLM Group Energy





Time Difference between Radiometer and GLM16 Candidates

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

- GLM Candidate (C) – A single GLM group identified within the radiometer's FOV and 30km range that strongly aligns with radiometer signal and timing.
- Miss – Absence of GLM16 and GLM18 single GLM groups 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 GLM groups 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

Time Difference between Radiometer and GLM16 Candidates

Table 1. Time Difference between Radiometer and GLM16 Top Candidates

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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

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  - 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

Time Difference between Radiometer and GLM18 Candidates

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

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- Hit – GLM16 and GLM18 single GLM groups 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

GLM16 and GLM18 Comparison

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

GLM16 and GLM18 Comparison

Table 3. Summary of GLM16 and GLM18 Differences

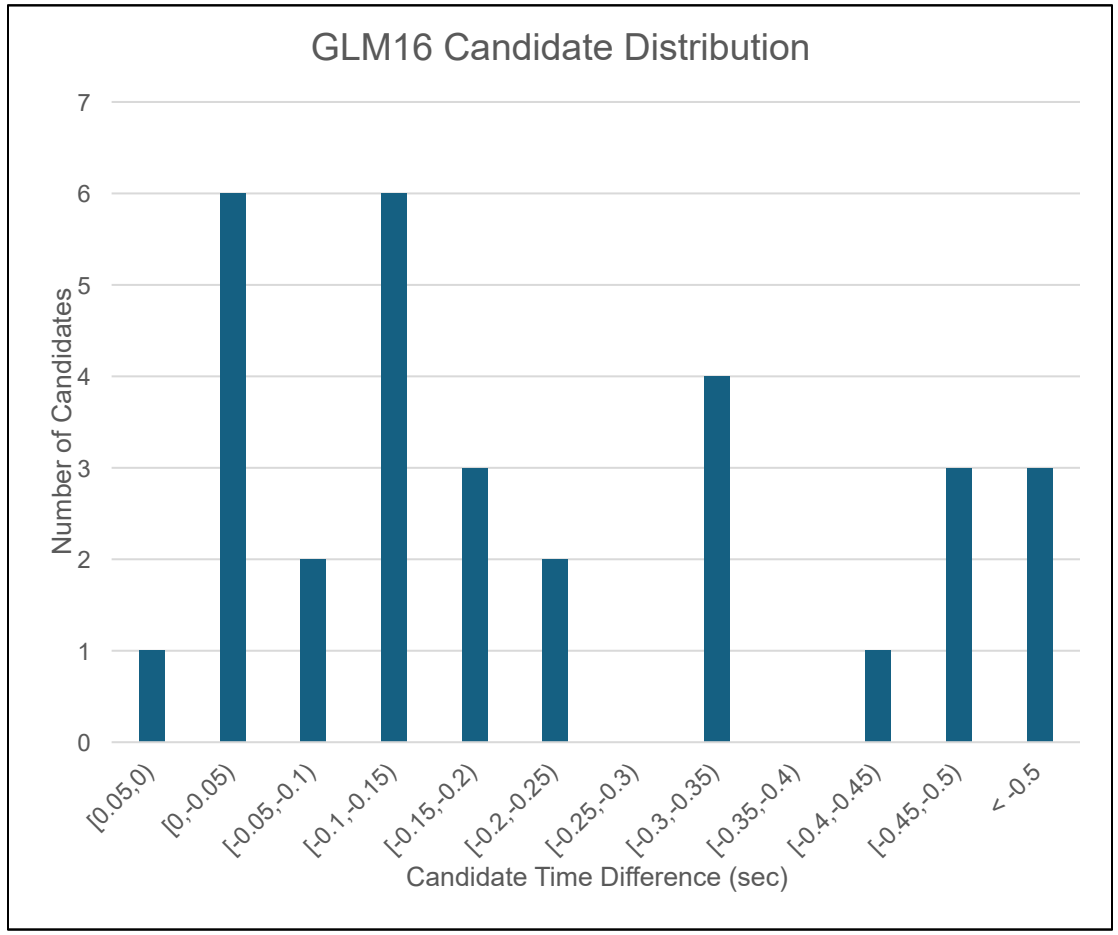
IRIG (HH:MM:SS.FFFF)	GLM16 Proposed Detection	GLM18 Proposed Detection	GLM16 Distance (km)	GLM 18 Distance (km)	GLM16 Event Classification	GLM18 Event Classification
21:42:37.7030	Miss	Miss	-	-	Miss	Miss
21:44:35.7140	Hit	Hit	26.187	23.218	Stroke	Stroke
21:45:01.4788	Miss	Miss	61.905	54.219	Miss	Miss
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

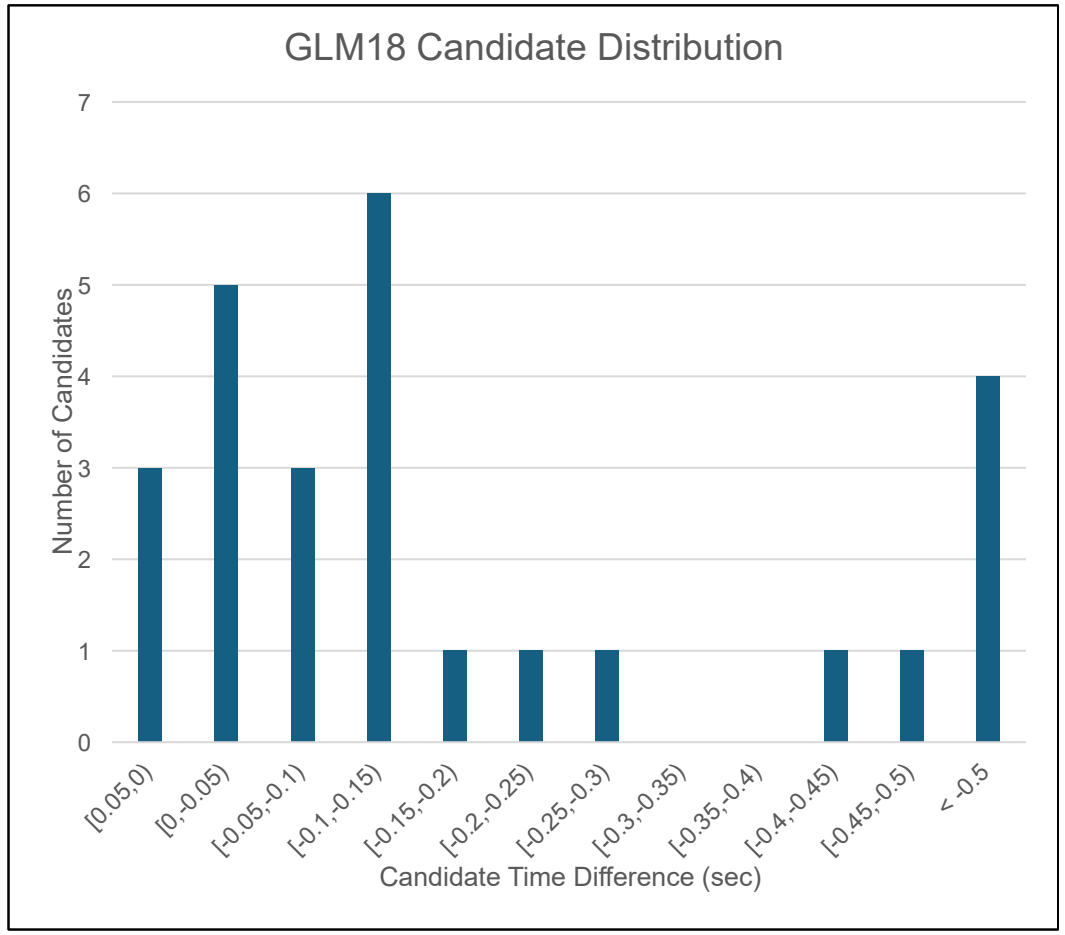
GLM16 and GLM18 Comparison

Table 3. Summary of GLM16 and GLM18 Differences

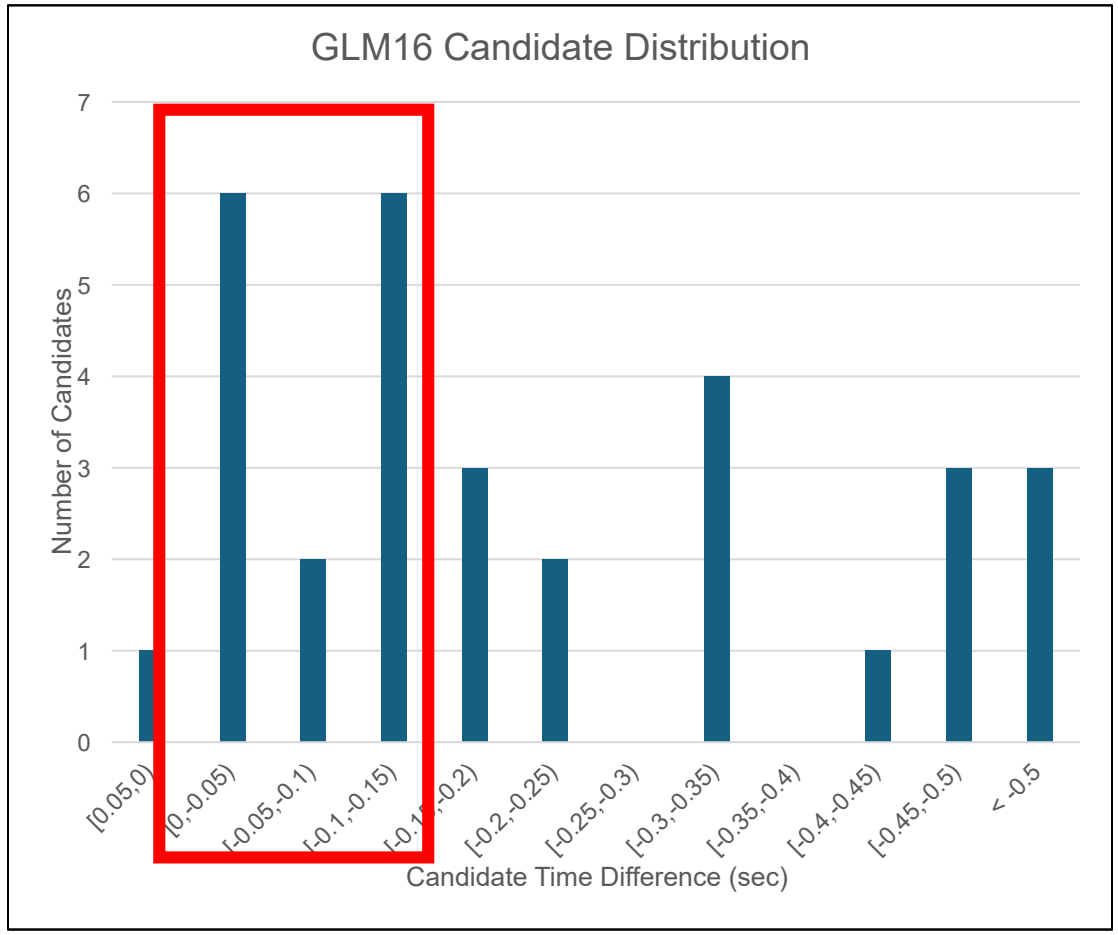
IRIG (HH:MM:SS.FFFF)	GLM16 Proposed Detection	GLM18 Proposed Detection	GLM16 Distance (km)	GLM 18 Distance (km)	GLM16 Event Classification	GLM18 Event Classification
21:42:37.7030	Miss	Miss	-	-	Miss	Miss
21:44:35.7140	Hit	Hit	26.187	23.218	Stroke	Stroke
21:45:01.4788	Miss	Miss	61.905	54.219	Miss	Miss
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

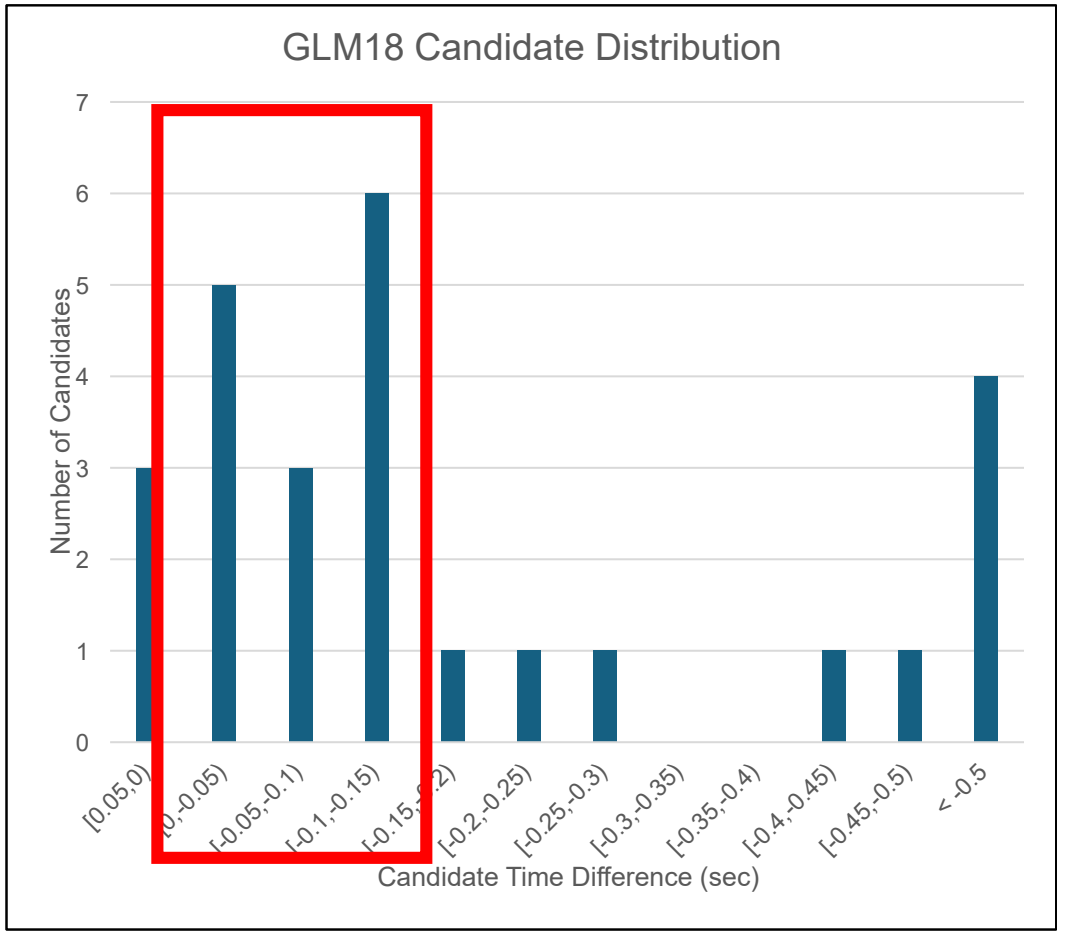
GLM Candidate Distributions





GLM Candidate Distributions





Conclusions

- Corresponding group data suggests that the radiometer and GLM saw the same events in most cases.
  - Radiometer pulses can be matched to events detected by GLM16 and GLM18 for 8 out of 13 timestamps on 05/28/2024
  - The timing difference between radiometer and GLM is shown to be within 0.0005 and -0.15 seconds
  - A radiometer distance of detection that matches with GLM is between 5km and 30km

Next Steps

- Filter through GLM Candidates to determine a best match
  - Use GLM stereo navigation algorithm to calculate average altitude between GLM16 and GLM18 candidate
  - Compare Lightning Mapper Array (LMA) data to radiometer and GLM data
- Determine if GLM has a lightning detection threshold that corresponds to events measured by the radiometers (i.e. cloud-to-ground events)
  - Review timestamps that have radiometer pulse and a lightning image but no GLM match
  - Analyze radiometer signal peaks and signal peak ratios
- Process more radiometer data as it becomes available to ensure validity in results and conclusions