Gigantic Jets Observed from Geostationary Orbit

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Abstract

Gigantic jets (GJs) are a type of transient luminous events [Pasko, 2010; Liu et al., 2015a]. They are electrical discharges that exit the tops of thunderstorms and reach 70-90 km altitudes [Pasko et al., 2002; Su et al., 2003], capable of transferring tens to hundreds of coulombs of charge between the thundercloud and the ionosphere [Cummer et al., 2009; Lu et al., 2011; Liu et al., 2015b]. Most observations of gigantic jets come from ground-based low-light-level optical cameras. This observation method is not ideal for monitoring GJ activity, as the camera must have a clear view of the region above thunderclouds. An optimal viewing condition is often unavailable during potential GJ producing storms, because those storm systems (tropical systems at low latitudes) are normally accompanied by substantial areas of stratiform clouds. GJs have also been observed by space-based instruments including the Imager of Sprites and Upper Atmospheric Lightning (ISUAL) onboard the FORMOSAT-2 satellite [Chen et al., 2008]. While ISUAL had dedicated instrumentation to observe GJs, it likely missed a lot of GJ events due to its limited coverage from the low Earth orbit of FORMOSAT-2. However, with the relatively high-resolution imaging capability from the geosynchronous orbit provided by the Geostationary Lightning Mapper (GLM) [Rudlosky et al., 2018], new opportunities are available to detect GJs.

GLM is a high-speed (2 ms) optical detector observing emissions in a narrow band at 777.4 nm. The high orbital altitude enables its CCD detector to continuously observe lightning and other terrestrial flashes across nearly an entire hemisphere with a relatively consistent pixel resolution (8 km at nadir and increasing to 14 km at the edge of its field of view) [Goodman et al., 2013]. Here we present the first GLM observations of GJs. The GJs occurred 200-500 km south of Puerto Rico from Tropical Storm Harvey, and were simultaneously recorded by a ground-based low-light-level camera from Puerto Rico. Unlike typical GLM flashes that consist of discrete optical pulses, GJ flashes contain long periods of sustained optical emissions in a fixed, small area in the GLM image. Most of the total optical energy is concentrated in a single GLM pixel in all frames of the GJ, which corresponds to the azimuth of the GJ in the ground-based video recordings. The GLM signatures of GJs may be unique enough to detect them by using only GLM and possibly low-frequency lightning networks, which could lead to total GJ detection across the huge GLM spatial domain.

Introduction

Photo credit: Jeff Miles

- Gigantic Jets (GJs) are electrical discharges that initiate as lightning inside a thundercloud and exit the storm top, propagating upward to lower ionosphere (70-90 km altitude) [Pasko et. al., 2010; Liu et al., 2015a]
- They are primarily detected by ground-based video cameras
  - Many constraints: clouds, small spatial viewing area, limited number of cameras
- Tens of GJs or less are detected each year, but the Imager of Sprites and Upper Atmospheric Lightning (ISUAL) campaign predicts over 5,000 per year [Chen et al., 2008]
- It's possible that with new observation techniques, many more GJs will be detected
- This can allow detailed studies of their climatology and of the storms that produce them

Instrumentation

- The Geostationary Lightning Mapper (GLM) is a high-speed (ms) optical detector in Geostationary orbit on board the GOES-16 and GOES-17 satellites [Goodman et al., 2013]
- It observes lightning through the 777.4 nm (OI) band during both day and night, over nearly a hemisphere
- The GLM pixel size is 8 km at nadir and increases to 14 km at the edge of its field of view
- GLM on board GOES-16 (GOES-17) covers North and South America (Pacific Ocean)

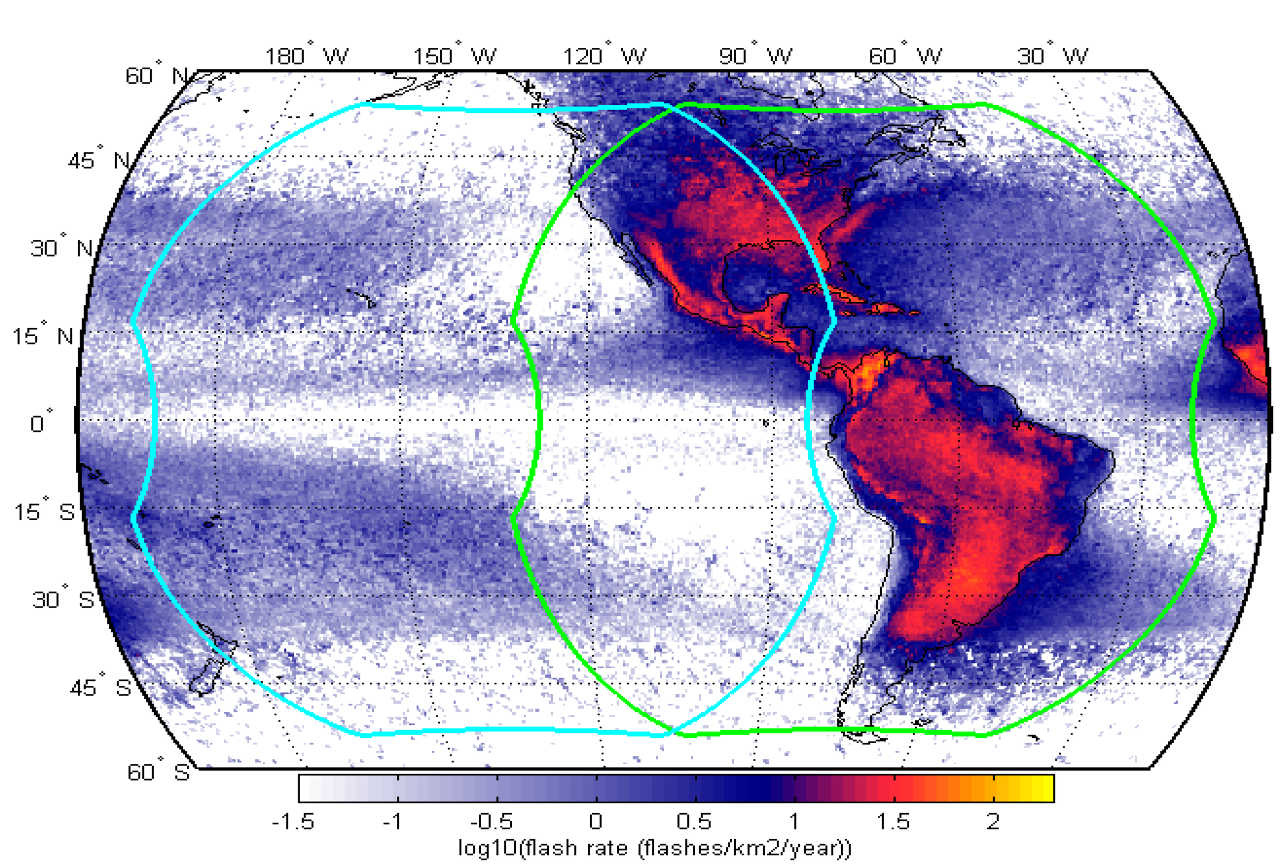

Figure 1. GLM flash rate with GLM field of view overlaid as green outline (GOES-16) and blue outline (GOES-17). [Rumpf et al., 2019, doi: 10.3390/s19051008]

Observations

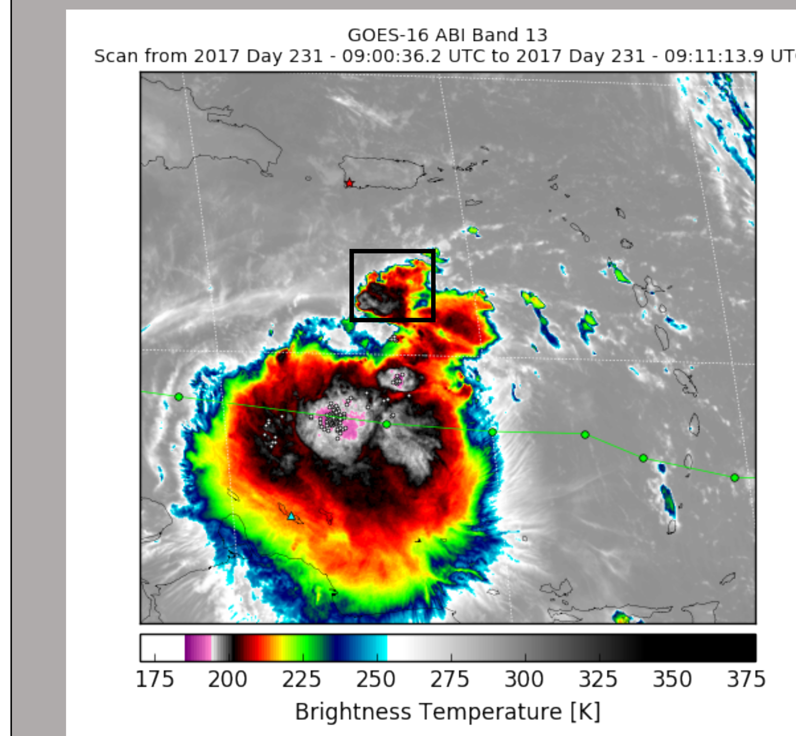

Figure 2. GOES-16 channel 13 brightness temperature for Tropical Storm Harvey when it was south of Puerto Rico and near the time of the GJ shown below (Figure 3).

- On 19 August 2017 Topical Storm Harvey produced fourteen GJs while it was south of Puerto Rico (Figure 2)
- A low-light ground-based camera operated by independent researcher Frankie Lucena captured the GJs
- Most of the GJs were clearly identified in the GLM level 2 data
- Most of the GJs occurred close to the center of the circulation, but the last two occurred in convective cells to the northeast of the circulation (black box in Figure 2)

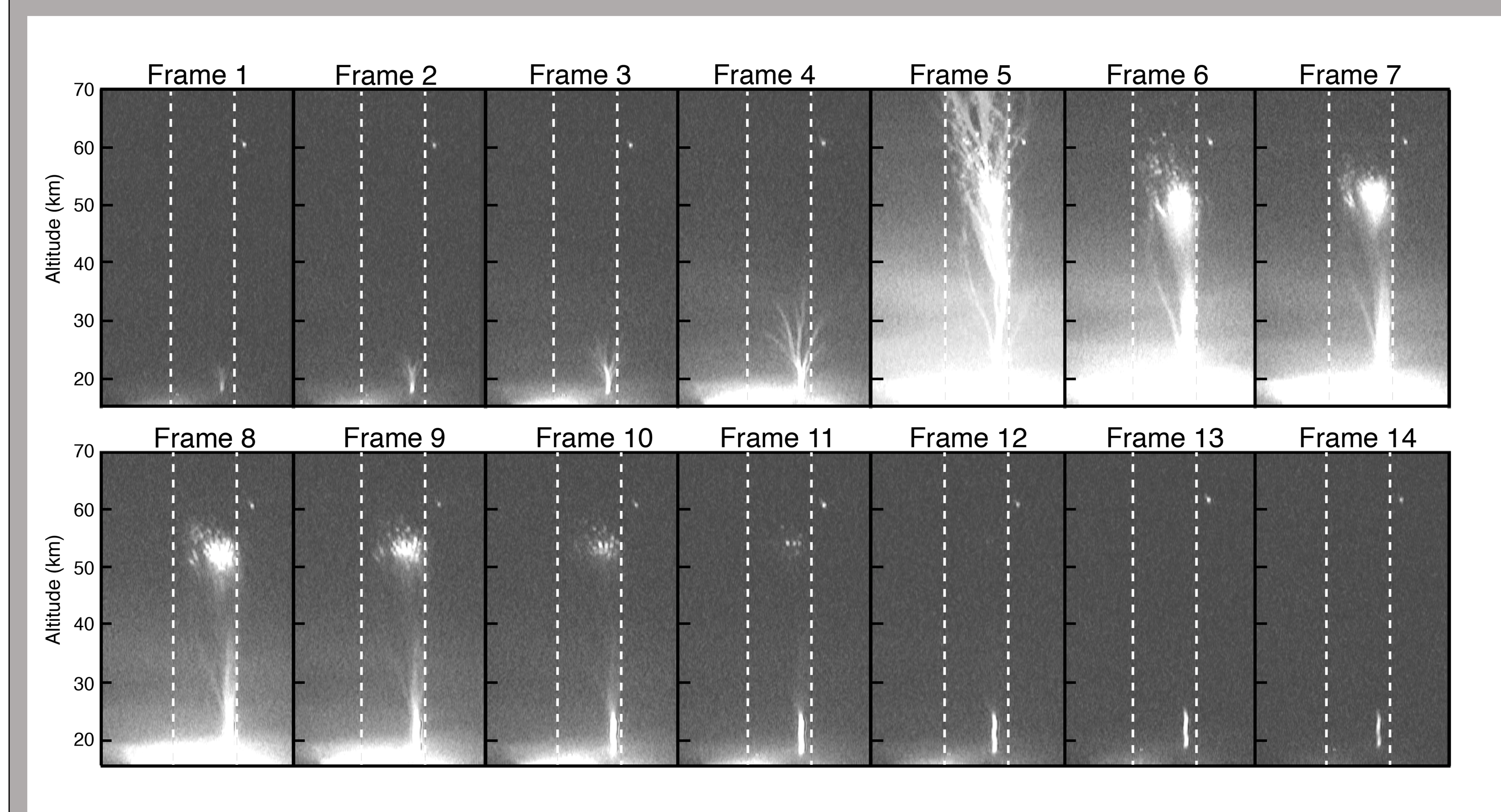

Figure 3. The GJ that occurred at 08:46 UTC. Each panel is a frame from the video images and lasts 33 ms. The dashed white lines correspond to the edges of the GLM pixel with the largest optical energies.

- The 08:46 UTC GJ (Figure 3) lasts fourteen video frames (462 ms) but GLM only registers detections for six video frames (198 ms)
- The GLM pixel with the largest optical energies (white box, Figure 4) corresponds to the azimuth of the GJ in the video images
- The peak in optical energy occurs when the GJ connects with the ionosphere (Figure 5)

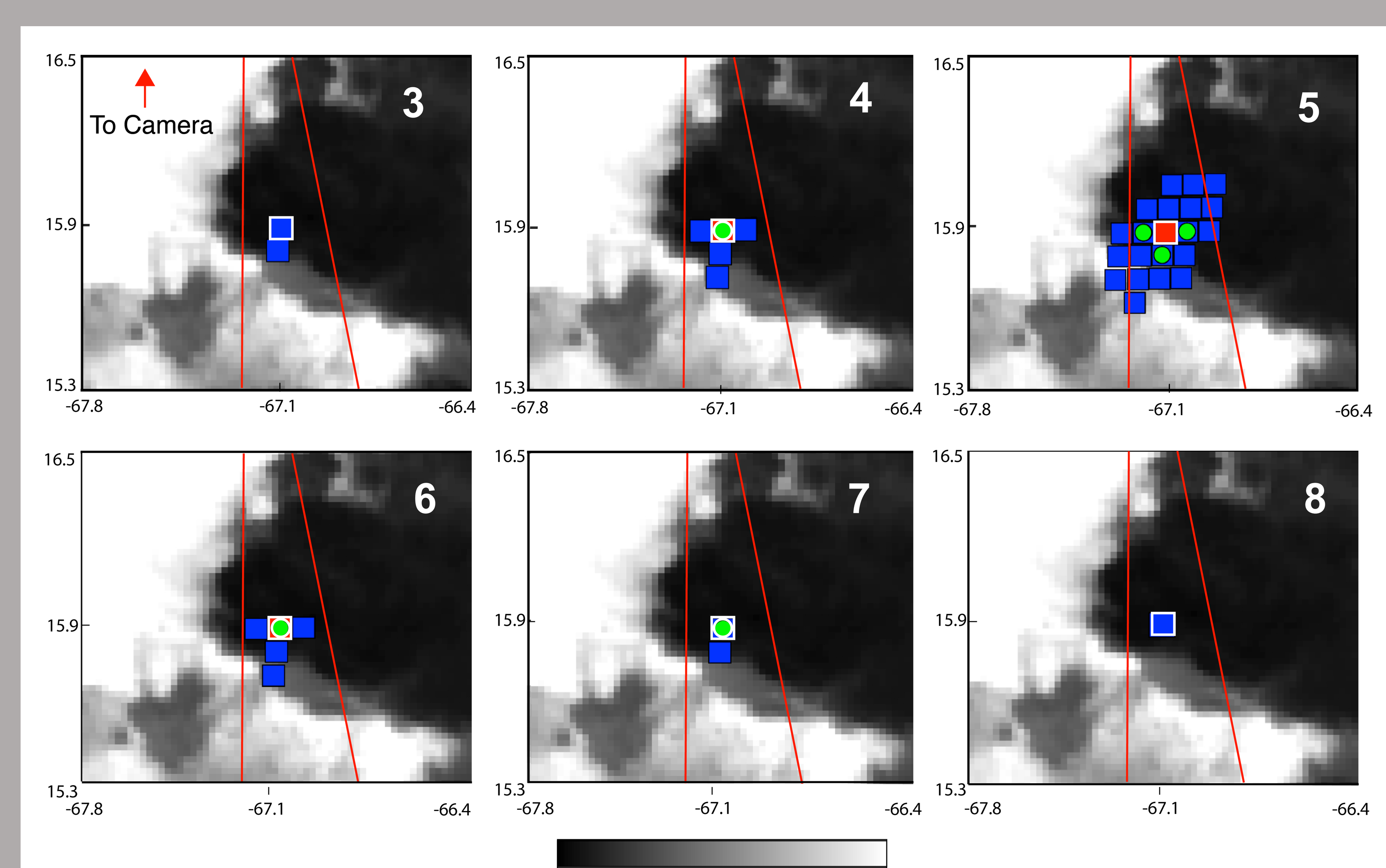

Figure 4. GOES-16 channel 13 brightness temperatures with GLM detections (colored shapes) overlaid for each video frame. The blue, green, and red detections correspond to optical energies of <10 fJ, 10-20 fJ, and > 20 fJ. The red lines correspond to the horizontal field of view of the ground-based camera.

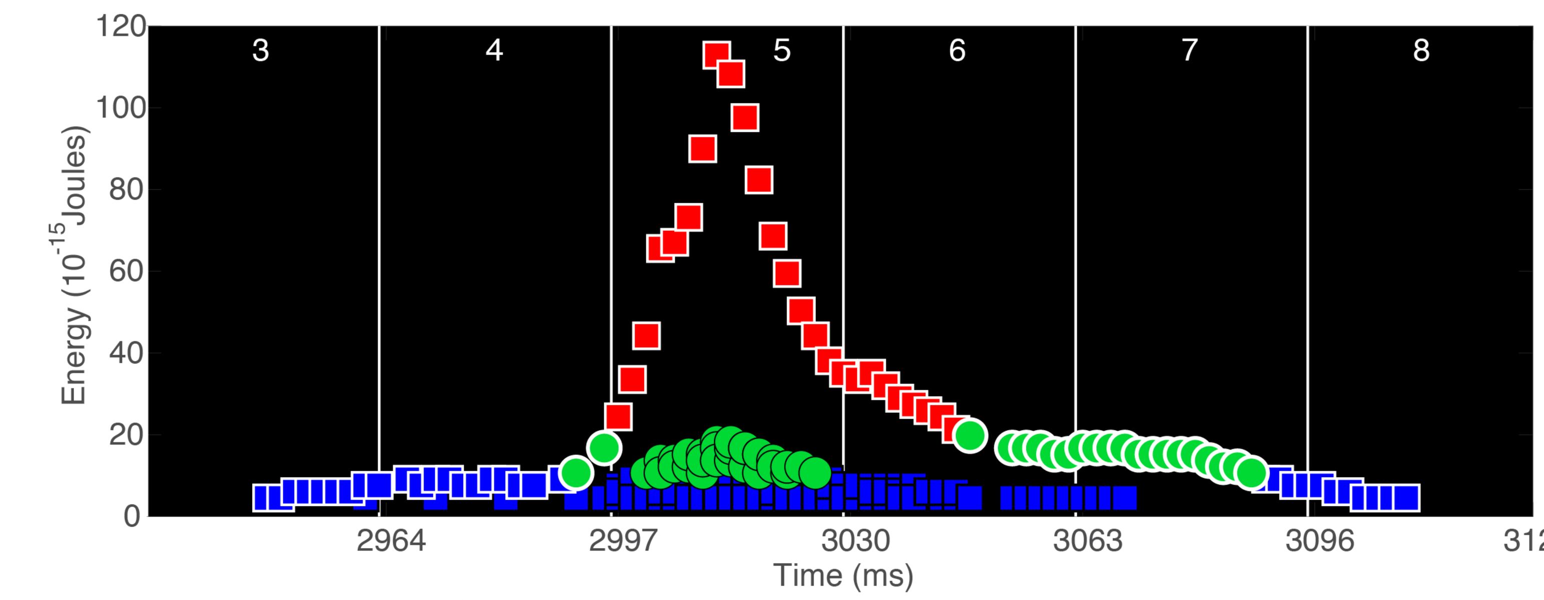

Figure 5. Time series of GLM detections for the 08:46 UTC GJ (Figures 3 & 4). Each color represents a different optical energy, with blue being < 10 fJ, green 10-20 fJ, and red > 20 fJ. The white outlined shapes correspond to the azimuth of the GJ from the video images.

UTC Time	Max Series Duration (ms)	Max Event Radiance (fJ)	Flash area (km)	Max Flash Radiance (fJ)	Max Group distance (km)	Flash duration (s)
Gigantic Jet Flashes						
4:19:54	44	21.3	652.5	494.4	10.1	0.486
4:21:15	42	16.7	801.8	828.6	10.1	0.224
4:24:46	168	48.8	726.1	1362.7	12.7	0.708
6:12:39	52	28.9	804.9	862.1	2.0	1.18
6:39:01	56	16.4	499.7	117.5	3.7	0.044
7:01:53	20	41.2	1179.4	1039.2	2.0	0.64
7:18:33	18	24.4	1254.3	682.1	2.8	0.886
7:25:41	16	13.7	821.9	225.8	20.4	0.196
8:14:38	24	16.7	502.7	57.9	12.9	0.028
8:46:02	160	112.9	1709.2	3067.2	2.5	0.724
8:50:16	100	28.5	879.8	1030.0	6.4	0.444
mean:	**64**	**33.6**	**893.8**	**887.9**	**7.8**	**0.505**
SD:	**55**	**28.5**	**359.5**	**833.1**	**6.0**	**0.364**
All GLM Flashes for 08/19/2017						
mean:	**7**	**23.8**	**1003.6**	**377.5**	**16.8**	**0.295**
SD:	10	34.6	609.02	632.6	12.4	0.262

Table 1. GLM properties of GJ flashes and all other flashes for 19 August 2017.

- Max series duration, which is the duration of continuous emission, is on average almost ten times that of other GLM flashes.
- The average flash optical energy for GJs is about double that of other GLM flashes
- The max group distance, which is a proxy for the lateral size of the flash, is approximately half that of other GLM flashes.

Summary and Conclusions

1. All the largest optical energies come from a single GLM pixel, which corresponds to the azimuth of the GJ channel
2. The GJ signatures include long continuous emissions, large peak flash energies, and small lateral propagation distances
3. Due to the differences between the GJ signatures and other flashes in the GLM data, it should be possible to write algorithms for large scale GJ detection when in combination with other data

- The findings from 1. and 2. may suggest that GLM is observing the GJ channel above the cloud

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