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An Analysis of the Lightning Jump Algorithm Using Geostationary Lightning Mapper Flashes

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***Abstract*— This project aims to implement the two-sigma lightning jump algorithm (LJA) developed using Lightning Mapping Arrays (LMAs), with GOES-16 Geostationary Lightning Mapper (GLM) flashes, evaluate its performance, and identify any needed adjustments to the algorithm to optimize operational skill. The GLM is projected to have lower detection efficiency (DE) (70-90 percent) than operational LMAs (95-99 percent). The reduced GLM DE coupled with the coarser spatial resolution of the GLM could have impacts on flash rates and trends that could affect the LJA in various ways. Deep dives are conducted on four separate cases. Three of four cases show LMAs seeing two to three times as many flashes as the GLM. Only fifteen of twenty five GLM jumps saw increases in radar intensity while fourteen of nineteen LMA jumps did. These results suggest a larger sample sized study must be conducted to determine how to implement the LJA with the GLM.**

Keywords—Geostationary Lightning Mapper; Lightning Jumps; Lightning Mapping Array; GLM; LMA; Severe Weather; LJA

I. Introduction

Lightning's relation to severe weather has been studied at least as far back as the late 1980's [Goodman et al. 1988, MacGorman et al. 1989]. More recent advancements in technology have brought forth Lightning Mapping Arrays (LMA) [Rison et al. 1999] that can detect 95% or greater of total lightning (intra-cloud and cloud-to-ground lightning flashes) within a 100 km range [Chmielewski and Bruning 2016]. Using total flash rate measurements from LMA, an automated algorithm named the Lightning Jump Algorithm (LJA) was developed with the purpose of predicting severe weather by measuring rapid, two-sigma increases in total lightning [Schultz et al. 2009]. The largest drawback of this algorithm is the restraint of the relatively small field of view (FOV) of LMAs.

With the 2016 launch of the Geostationary Lightning Mapper (GLM) on board the GOES-16 satellite there is now access to hemispheric total flash rate data. Despite coarser spatial resolution versus LMAs coupled with other potential challenges for the GLM such as; flashes with a bright background during the day, low altitude flashes, and accurately separating relatively small flashes in higher flash rate storms, the GLM is theorized to detect 70%-90% of total lightning [Goodman et al. 2013]. Due to its relatively high DE given its wide FOV, the GLM is a good candidate to apply the LJA to in the near-future.

Recalling that the LJA was originally built and tested to run on LMA networks, it is important to understand the differences between LMAs and the GLM. Along with the lower DE of the GLM due to the aforementioned reasoning, the two instruments are also measuring completely different properties of lightning. LMAs detect sources of very high frequency (VHF) electromagnetic radiation produced by lightning, while satellite based instruments, like the GLM, detect optical radiation produced by lightning [Nag et al. 2015]. Due to these differences it is important to distinguish between GLM and LMA performance to identify any needed adjustments to the LJA to optimize operational skill of the LJA with the GLM.

II. Data and Methodology

A. Lightning Data

The lightning data in this project come from multiple sources. Most notably, flash and group rate data from the GLM are used. This GLM data are from the Lockheed Martin reprocessed dataset that corrects some of the navigational and timing issues currently in the operational datasets [Personal Communication, Doug Mach, 2017]. In addition, raw VHF source data from three LMAs were used: the North Alabama Lightning Mapping Array (NALMA) [Koshak et al. 2004], the Colorado Lightning Mapping Array (COLMA) [Lang et al. 2014], and the Oklahoma Lightning Mapping Array (OKLMA) [DiGangi et al. 2016].

B. Radar Data

Level II NEXRAD WSR-88D radar data are used for both cell tracking and comparisons to lightning data. The data are obtained through the National Centers for Environmental Information (NCEI) radar archive. The data are gridded into 0.009° x 0.009° x 1 kilometer grid boxes.

C. Environmental Data

The Rapid Refresh (RAP) model is used to define the environment in each case. Environmental data are updated every hour on the hour for the entire case. They are also gridded into the same grid as the LMA flashes and radar data at 0.009° x 0.009° x 1 kilometer grid boxes. These data are mainly used for the calculation of the maximum expected size of hail (MESH).

D. LMA Flash Clustering and Cell Tracking

All gridding, radar calculating, flash clustering, and cell tracking are done within the Warning Decision Support System – Integrated Information (WDSS-II) framework [Lakshmanan et al. 2007]. The LMA flash clustering is done by using the default w2lmaflash algorithm. In this algorithm, six stations must detect a source for it to be considered real and a minimum of 10 sources are required for a flash.

For cell tracking, an automated algorithm named VILFRD, developed by Schultz et al. [2016], is used alongside WDSS-II's w2segmotionll. VILFRD uses a combination of vertically integrated liquid (VIL) and five minute average GLM flash rate densities (FLCT5) to assign values to and track storms. This algorithm tracks more based on radar data when flash counts are low and vice versa. How to calculate VILFRD is shown in (1).

$$\text{VILFRD}=100 \text{ X} \left[\left(\frac{\text{VIL}}{45}\leq 1\right)+\left(\sqrt{\frac{\text{FLCT5}}{45}}\leq 1\right)\right] \quad (1)$$

III. RESULTS

A. Skyline, AL Supercell 22 April 2017

This storm was a long-lived supercell that tracked from West-central Tennessee down through Northeastern Alabama where it produced swaths of wind and hail damage as well as a brief EF-0 tornado in Skyline, AL at 2240 UTC. Fig. 1 A-B show the lightning and radar trends respectively for this particular storm during its entire path through the 125km range of the NALMA. The first thing to note is how the LMA is detecting significantly more flashes than the GLM (up to 2-3 times the amount) throughout most of the period. In the period between 2100 UTC and 2200 UTC there is a decrease and local minimum in GLM groups and flashes while the LMA holds fairly steady at a high flash rate. During this same period there is the most growth in this storm via MESH and VIL values. During this period of intensification the LMA identified four separate lightning jumps while the GLM identified only two.

Moving forward to just before tornadogenesis there is an increase, local maximum, and lightning jump in GLM flashes at 2225 UTC. This jump occurs just a few minutes prior to increases in MESH and VIL and fifteen minutes prior to tornadogenesis. Also interesting to note is that after this jump there is a significant decrease in GLM flashes to another local minimum leading up to the tornado. Meanwhile the LMA did not detect an increase and jump until 2236 UTC or four minutes prior to tornadogenesis. This increase in LMA lightning lines up almost exactly in time with the increase in the radar variables. The LMA flash rate continues to increase through tornadogenesis, unlike the diving GLM flashes.

Overall the LMA saw nine jumps throughout the entire period while there were ten jumps in GLM flashes. Out of all of these jumps there were only three jumps between the LMA and GLM flashes that were within ten minutes of each other. However, both instruments saw jumps within fifteen minutes of tornadogenesis.

B. Jones Chapel, AL Supercell 22 April 2017

The Jones Chapel supercell was another long-lived storm that tracked through the northern half of Alabama. It produced an EF-1 tornado in Jones Chapel, AL at 2240 UTC, the same time as the Skyline tornado. Fig. 1 C-D shows the lightning and radar trends respectively. Once again the GLM is detecting a lot less (2-3 times less) flashes than the LMA. There are areas where the trends between GLM flashes and LMA flashes are similar such as in the period of 2130 UTC to 2220 UTC. However, in that same period of similar trends the GLM flashes saw three lightning jumps while LMA only saw one. Two of the GLM jumps are associated with increases in MESH and VIL while the other one actually coincided with a notable decrease in radar derived intensity. The lone LMA lightning jump was associated with one of the increases in radar derived intensity. There are also periods where the trends are different between GLM flashes and the LMA. Between 2300 UTC and 2330 UTC there is a significant decrease in LMA flashes while there is a slight increase in GLM flashes. During this time there were two GLM lightning jumps to zero from the LMA. Only one of these GLM jumps was associated with an increase in radar derived intensity.

In terms of tornadogenesis, the LMA and GLM flashes both saw a lightning jump at 2236 UTC, four minutes before the tornado. Both of these jumps were just prior to a relatively large increase in both MESH and VIL. Once again GLM flashes begin to dive directly after this jump into tornadogenesis where the LMA flashes actually continue to increase throughout the tornado.

Throughout the entire lifecycle of this storm, there were eight lightning jumps in GLM flashes and only four in LMA flashes. Only five of the GLM lightning jumps saw an associated increase in radar derived intensity, while all but one of the LMA jumps saw this association. Out of all of the jumps there were only two instances of a GLM and LMA jump being with ten minutes of each other.

C. Denver, CO Supercell 08 May 2017

This supercell was a part of a billion dollar hail event in Colorado on 08 May 2017. This particular cell dropped hail as large as 2.75 inches in downtown Denver, CO. Fig 1 E-F show the lightning and radar trends, respectively, during the time this cell was within the COLMA operational range. Early work by

Rutledge et al. [2017] indicates that the storm was classified as having an anomalous charge structure during most of its life cycle. This is a challenge for the GLM as many of these flashes were occurring low in the storm meaning less light was escaping the cloud top. A prolonged period where the LMA is detecting two to three times as many flashes than the GLM is once again observed with these storms. For the most part the lightning trends are quite different, except for a brief period between 2120 UTC and 2140 UTC.

There were four lightning jumps seen by the LMA and all four of these jumps were associated with increases in VIL and MESH. This is consistent with work by Chronis et al. [2015] and Schultz et al. [2016]. Only one of these jumps coincided with the three jumps we saw in this period via GLM flashes. That one lightning jump in GLM flashes that had an associated LMA lightning jump was the only one of the three that saw associated increases in radar derived intensity.

D. Central Oklahoma MCS 17 May 2017

These radar and lightning data are from a portion of a larger MCS that went through Central Oklahoma after dark on 17 May 2017. This case differs from the previous three in that it was at night and it was not cellular. Fig. 1 G-H show the lightning and radar trends, respectively, for the time this storm was within OKLMA operational range. In this storm there was much better agreement between LMA flashes and GLM flashes than the previous three storms, and there was actually a prolonged period where the GLM was detecting more flashes than LMA. The trends between GLM flashes an LMA flashes are actually quite consistent through this case as well, which is again contrary to the previous three storms.

Despite the better agreement in trends and magnitudes of the flashes there was still a disparity in the timing and number of lightning jumps. There were four lightning jumps in the GLM flashes with only two lightning jumps in LMA flashes. There was only one time where there was a lightning jump in both LMA and GLM flashes within ten minutes of each other. Only three of the four GLM lightning jumps coincided with increases in MESH and VIL, while both LMA jumps coincided with MESH and VIL increases.

E. Correlations

Table 1 shows average correlations between the varying lightning datasets and radar variables. GLM Flashes and LMA flashes actually have a moderate correlation (~0.43) between them despite the large differences in magnitude throughout three of the four cases. Meanwhile there is very little correlation between GLM groups and LMA flashes (~0.2). LMA flashes were moderately correlated with the radar variables while GLM flashes were more loosely correlated and GLM groups had a near-zero correlation.

IV. Conclusions and Future Work

For three of the four deep dive cases vast differences between trends and magnitudes of GLM and LMA flashes were observed. These three cases were daytime supercells with relatively high flash rates. For these three cases LMA saw anywhere between two to three times more flashes than GLM on average. The outlying case was a relatively lower flash rate night time MCS where there was fairly good agreement between both the magnitude and trends of GLM and LMA flashes. There were times where lightning jumps between GLM and LMA flashes coincided, most notably just prior to both of the tornadoes produced by these storms, but for the most part there was little correlation. Out of twenty five GLM jumps and nineteen LMA jumps only seven of those were within ten minutes of each other. Fourteen of nineteen jumps in LMA flashes coincided with increases in the MESH and VIL values, while only about fifteen of twenty five the lightning jumps in GLM flashes saw those same increases in radar intensity. This difference is also highlighted in our correlation matrix where LMA flashes were much higher correlated to the radar variables than the GLM flashes. LMA flashes had Pearson correlation values of .47 and .42 for VIL and MESH respectively while GLM flashes only had values of .19 and .13. The large difference in these values aren't surprising given how the jumps lined up with radar metrics. The difference in the total number of jumps also isn't surprising as the average Pearson correlation value between GLM flashes and LMA flashes was only .44.

Due to the vast differences in trends, magnitude, and trends (or jumps) between GLM and LMA lightning flashes there needs to be a larger sample size study conducted utilizing the LJA with GLM flashes using similar methods that were used in the original development of the LJA with LMAs (e.g., Schultz et al. 2009). This larger sample size study will compare GLM flashes with radar derived intensity metrics as well as storm reports. This will allow for a more in depth look into metrics like false alarm rates between the two datasets given that there were a much higher percentage of GLM jumps not seeing increases in radar intensity metrics than LMA jumps. Sensitivity testing on this dataset will need to be done to determine if two-sigma and the minimum ten flashes per minute thresholds will still yield the best results while using GLM flashes. Final results of this sensitivity testing will be compared to values obtained in previous LJA studies with the LMA to better understand the possible operational utility of a LJA with GLM flash data. A LJA study with GLM groups may also be conducted in a similar manner, but its lower correlation with LMA flashes and near-zero correlation with radar variables may make that a more challenging task.

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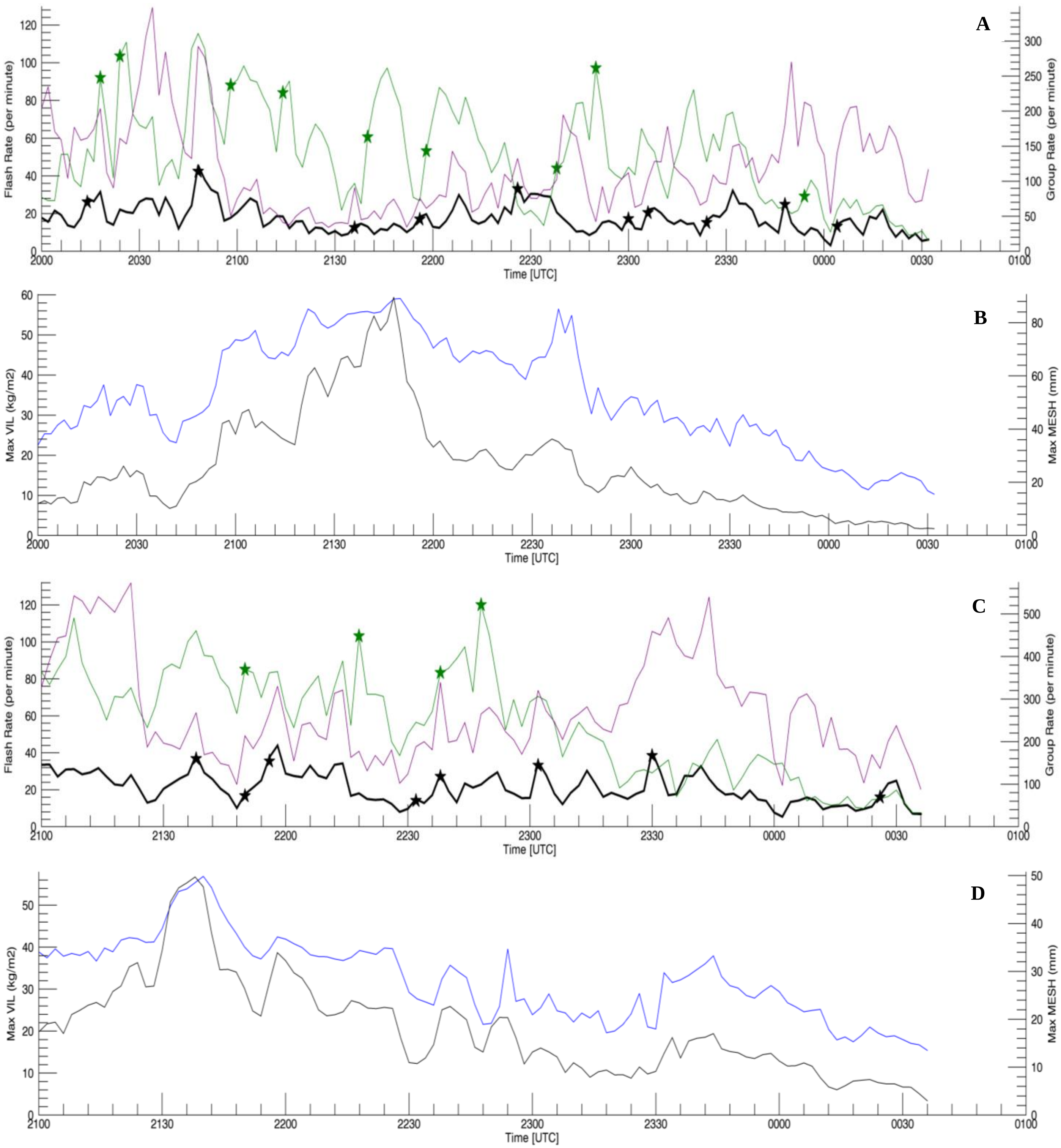
Table 1.

	Average Pearson Correlations				
	LMA Flashes	***GLM Flashes***	***GLM Groups***	***VIL***	***MESH***
LMA Flashes	1	0.43813	0.15814	0.47142	0.421943
GLM Flashes	0.43813	1	0.62890	0.19602	0.13742
GLM Groups	0.15814	0.62890	1	-0.04369	-0.05089
VIL	0.47142	0.19602	-0.04369	1	0.69456
MESH	0.42194	0.13742	-0.05089	0.69456	1


A
Flash Rate (per minute)
Group Rate (per minute)
Time [UTC]
B
Max VIL (kg/m2)
Max MESH (mm)
Time [UTC]
C
Flash Rate (per minute)
Group Rate (per minute)
Time [UTC]
D
Max VIL (kg/m2)
Max MESH (mm)
Time [UTC]

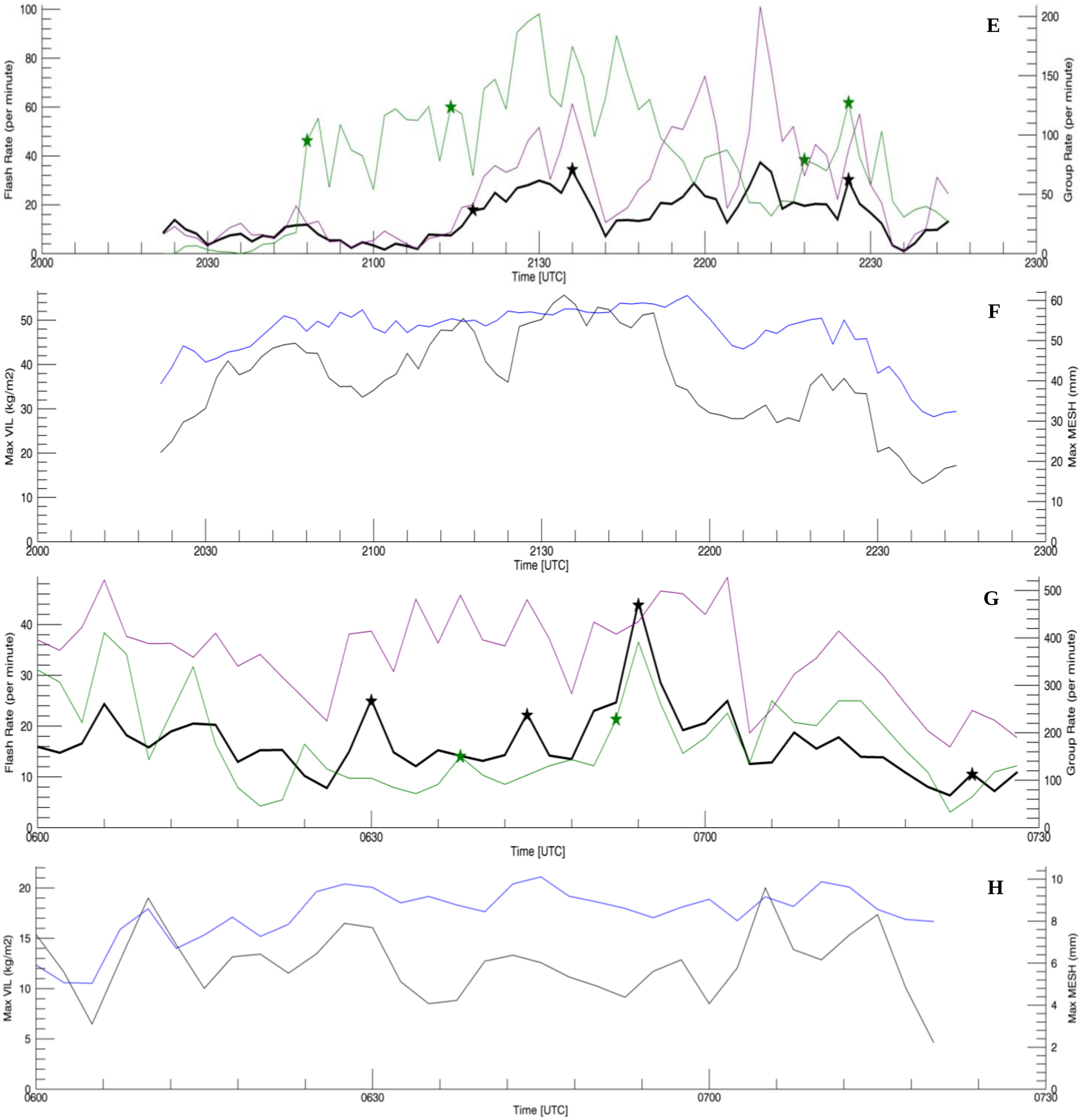


Figure 1: Time series plots of lightning and radar variables for each storm. A) Skyline, AL time series (UTC) of LMA flashes (green, flashes per minute), GLM flashes (black, flashes per minute), and GLM groups (purple, groups per minute). Black stars represent lightning jumps in GLM flash data and green stars represent lightning jumps in LMA flash data. Lightning jumps are not run on the GLM group data. B) Skyline, AL time series of maximum VIL (blue, kg/m2) and maximum MESH (black, mm). C-D is the same as A-B except for Jones Chapel, AL. E-F is the same as A-B except for Denver, CO. G-H is the same as A-B except for central Oklahoma.

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