THE GOES-R GLM LIGHTNING JUMP ALGORITHM (LJA): RESEARCH TO OPERATIONAL ALGORITHM

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INTRODUCTION

- Lightning Jump Algorithm (LJA) developed by Schultz et al. (2009, 2011) uses Lightning Mapping Array (LMA) data to suggest likelihood of subsequent severe weather

- Geostationary Lightning Mapper (GLM) on GOES-R will see flashes differently than LMA, yielding different flash counts and locations

- Full automation and testing needed before operational implementation and utilization

- *Robust and objective storm cell tracking needed in order to compute flash rate history / tendency*

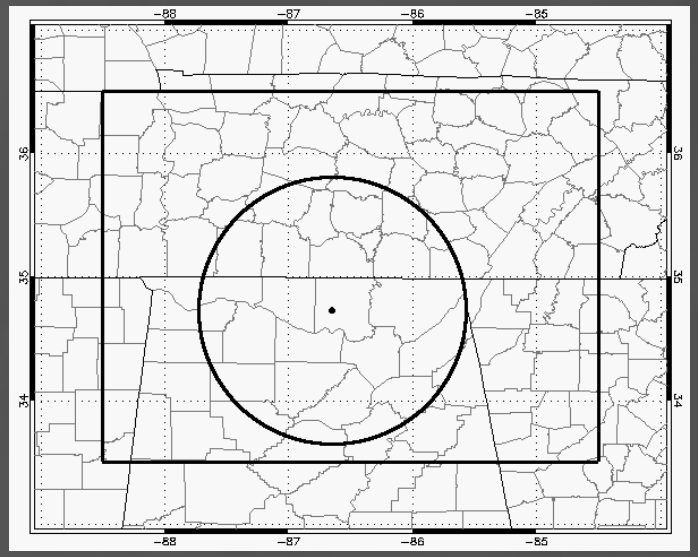
LJA PROJECT GOALS

- OBJECTIVE: To refine, adapt and demonstrate the LJA for transition to GOES-R GLM (Geostationary Lightning Mapper) readiness and to establish a path to operations
- Reduce risk in GLM lightning proxy, cell tracking, LJA automation, and data fusion (e.g., radar + lightning).
- Develop and refine a fully automated, *objective* cell tracking algorithm using lightning (GLM Proxy) and radar (VIL) for a large sample
  - Algorithm completely hands off with no manual corrections during processing
  - Warning Decision Support System - Integrated Information (WDSSII)

DATA SAMPLE SET

- Events included from 2002 through 2011
  - Subset of Schultz's current database
- Domain
  - Cell clusters tracked using WDSSII within larger domain.
  - Clusters included in database for the period (min. 30 min of lifetime) of lifetime that occurred within 120km of the LMA center

Domain



Scale	~Area (km2)
1	32
2	65
3	97
4	130
5	162
6	243

Various scales were tested during tracking in WDSSII

Scale	Event days	Clusters tracked	Storm reports	Severe clusters	Non-severe clusters**
1	104	1365	434	220	1145
2	102	1112	418	210	902
3	98	987	422	203	784
4	97	850	389	179	671
5	93	748	392	176	572
6	90	595	314	145	450

* Values for <10km report distance and 10 flashes/min threshold

**During time spent in domain

Automated objective tracking and LJA flow chart

Proxy GLM Data

- Developed by Monte Bateman and Doug Mach
- Each flash location is determined by an amplitude weighted centroid of the groups/events
- Grid to 0.08° x 0.08° at 1 min and 5 min running average every 1 minute.

RADAR Data

- Five closest radars merged and gridded to 0.009° (~1km) using WDSSII
- Data outputs: Composite reflectivity, VIL, VIL_Density, MESH, azimuthal shear (approx. every 2 – 4 minutes)

Combine Proxy and RADAR

- Combine VIL and 5-minute Proxy GLM flash rate density (FLCT5)
- Track values where VILFRD ≥ 20, using increments of 20, with anything over 100 set to 100.

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

Tracker (WDSSII w2segmotionll)

- Using VILFRD, builds clusters until a minimum size threshold is met. Several sizes/scales tested

First see if values exceeding 100 cover large enough area. *If not, include values exceeding 80 . If not, include values exceeding 60 , etc.*

Merge Tracks

- Merged tracks separated by < 15 km between time steps (1 minute).
- Tracks included in database with lifetimes ≥30 minutes

Lightning Jump Algorithm

Thresholds:

- Domain 120 km
- Algorithm spin-up
- 2 sigma

Variables:

- Flash rate threshold
- Scale/size

Storm Report Association

Thresholds:

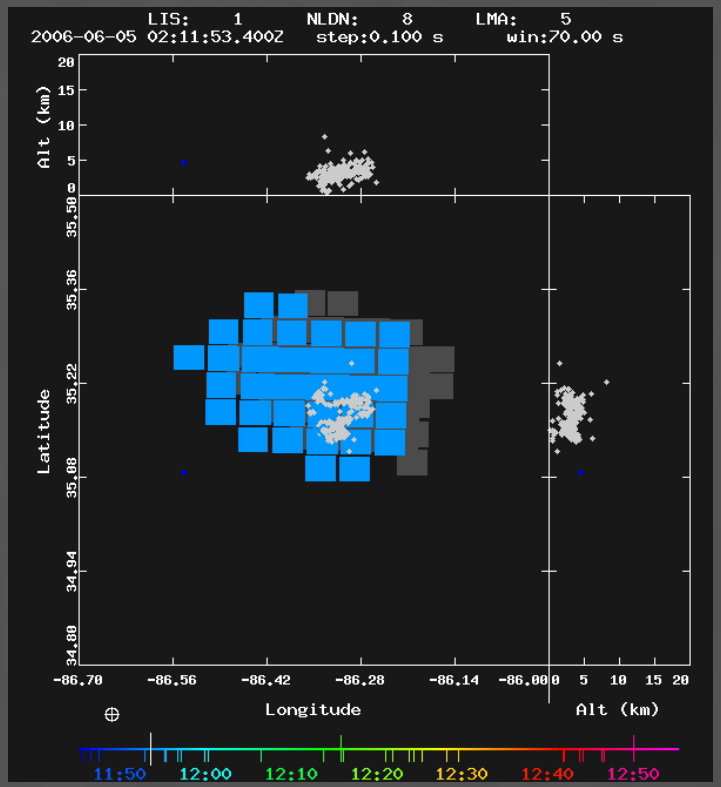
- Reports are grouped every 6 min
- 10 minute buffer after lightning data is cut off

Variables:

- Report associated within X distance of cluster

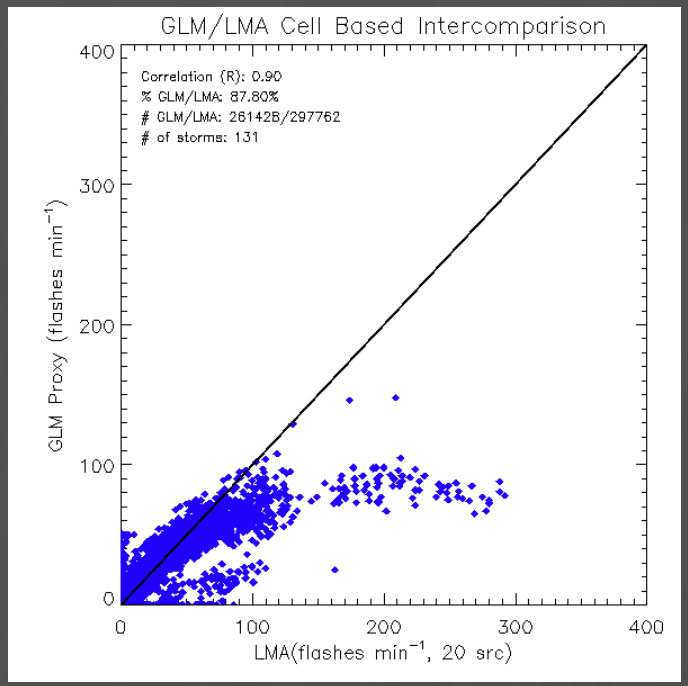
Verification

- Maximum 1 jump allowed every 6 minutes
- Storm reports can only confirm one forecast.
- Each report (after grouping) that occurs within a forecast period is considered a hit.
- When subsequent jump occurs during a forecast, only the time after the first forecast has expired is the subsequent forecast allowed to be verified. Otherwise it is a false alarm.
- Forecast/warning time set at 45 minutes



TRANSITION FROM LMA TO GLM PROXY

- Observations from LMA ≠ GLM
  - Different instrument
  - Different frequency
  - Different part of flash
- Must transition product from LMA to GLM proxy data stream
- Based on LMA flash rate, Monte Carlo look-up table to realistic optical events (LIS), and GLM cluster-filter algorithm.



- Compared 1-minute flash rates in LMA and GLM for 131 storms
  - 20+ sources per flash threshold
- GLM Proxy flash count is ~88% of the LMA flash count
- Correlation in the trends are strong (R=0.9)

CELL TRACKING

- Tracker (WDSSII *w2segmotionll*) builds cells until a minimum size threshold is met. Several size scales are tested ranging from ~30 to ~300 km^2.
- Tracking uses maximum overlap approach for associating cells from one time step to the next.
- Outside WDSSII, “broken tracks” are objectively merged. If WDSSII has a new cell begin at *t+1* within 15 km of where a previous cell track ended at time *t*, those cell histories are tied together.

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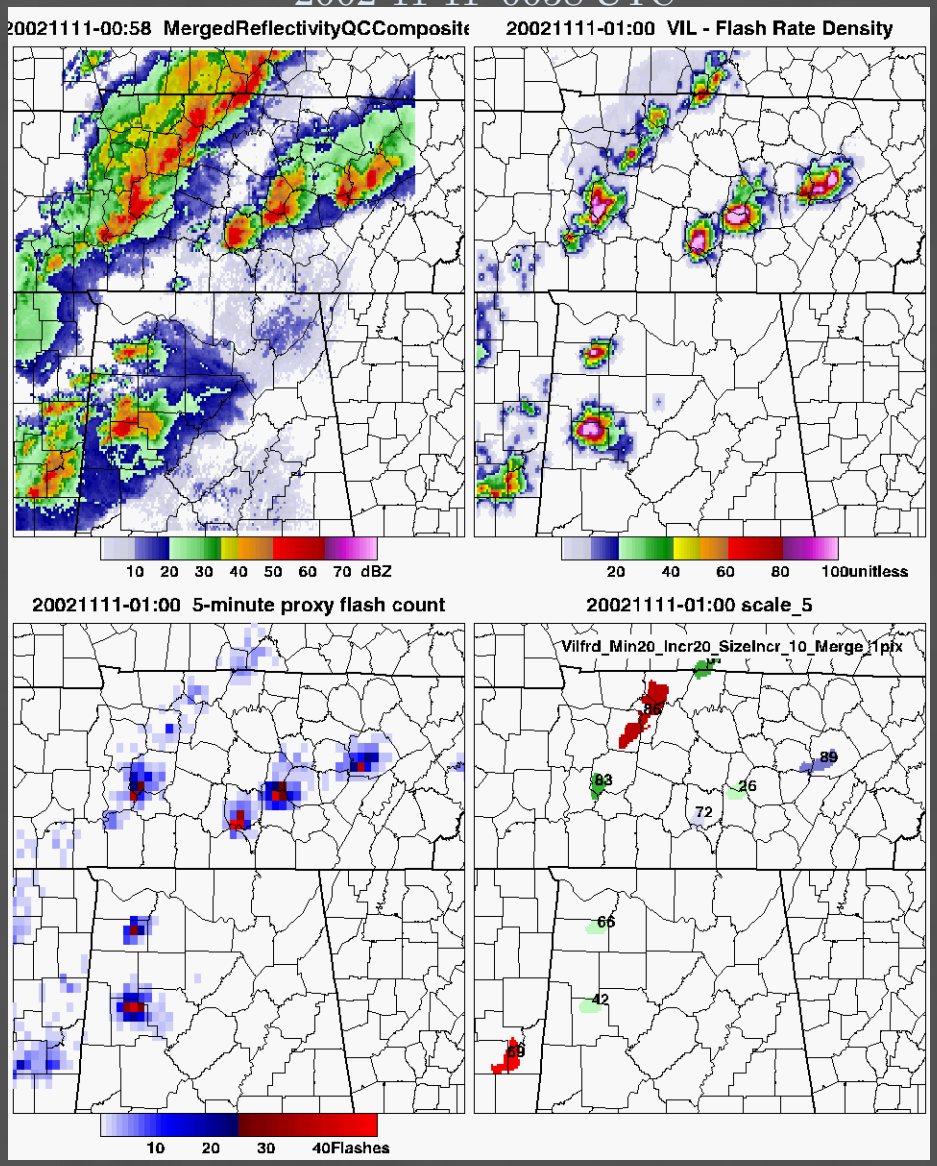


Flct5: 5-minute GLM proxy flash count, updated every min.
VIL: Vertically Integrated Liquid (radar)
VILFRD: VIL combined with 5-minute Flash Rate Density

$$VILFRD = 100 * (((VIL/45) \leq 1) + (sqrt(Flct5/45) \leq 1))$$

Lightning Jump Algorithm Overview – 2 sigma

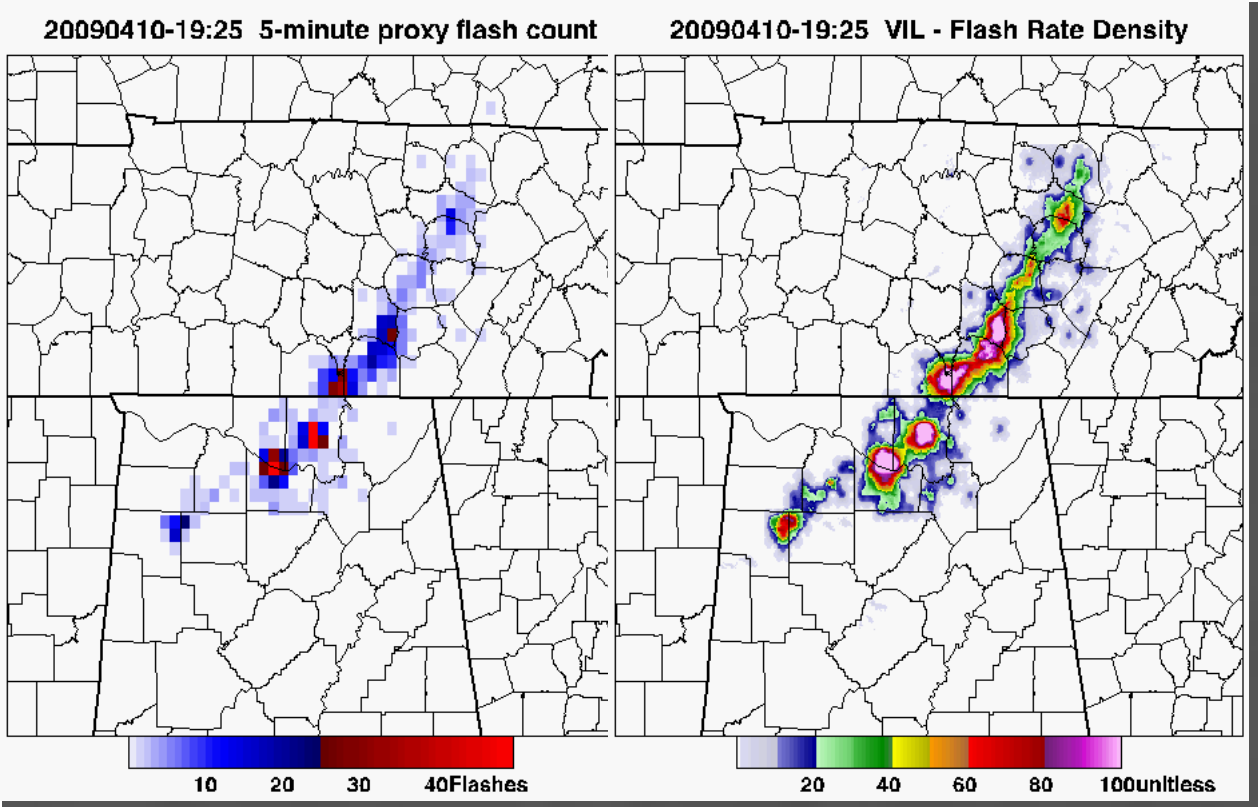
- First, 1 minute flash rates are averaged over two minutes:

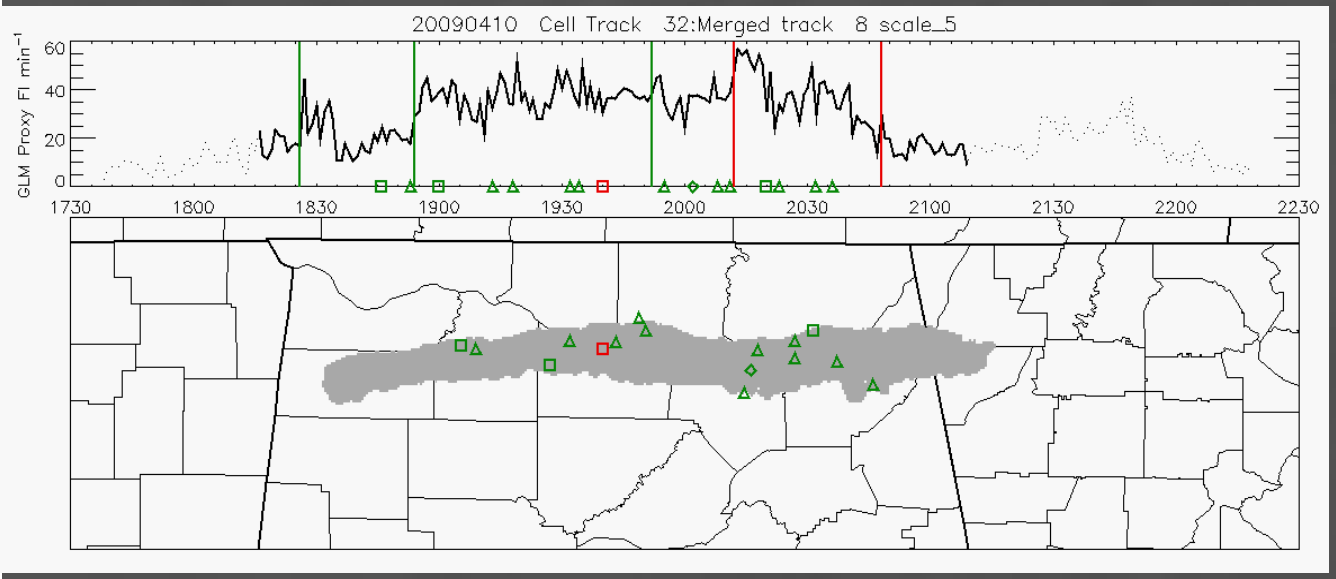
$$FR_{avg}(t_i)(flashes\ min^{-1}) = \frac{FR_{t1} + FR_{t2}}{2}.$$

- Next, the time rate of change of the avg. total flash rate (DFRDT) is calculated:

$$\frac{d}{dt}FR_{avg}(t_{i+1}) = \frac{FR_{avg}(t_{i+1}) - FR_{avg}(t_i)}{t_{i+1} - t_i} = DFRDT(flashes\ min^{-2}).$$

- A standard deviation (σ) is calculated from the most recent 5 periods of DFRDT (not including the current observation time) to determine the jump threshold at any given point in time. Twice this standard deviation value is the jump threshold.
- A jump occurs when DFRDT values increase beyond the jump threshold of 2σ and meets the flash rate threshold of 10 flashes min^{-1}.
- A jump ends when the DFRDT value drops below 0.





Example case

- Features in VILFRD (combine GLM Proxy and VIL) are tracked (e.g., top left)
- Lightning Jump Algorithm executed on individual clusters (e.g., bottom left)
- SPC Storm reports associated with cluster
- Verification methods applied.

SCALE VS. MAXIMUM REPORT DISTANCE FROM CLUSTER – POD:FAR

Maximum Report Distance for Verification

Scale	5	10	15
1	0.40 : 0.76	0.40 : 0.72	0.39 : 0.68
2	0.44 : 0.80	0.42 : 0.78	0.41 : 0.76
3	0.57 : 0.81	0.56 : 0.78	0.56 : 0.76
4	0.58 : 0.83	0.57 : 0.81	0.58 : 0.79
5	0.63 : 0.81	0.64 : 0.78	0.64 : 0.76
6	0.71 : 0.78	0.71 : 0.75	0.71 : 0.74

- Increasing distance to associate reports with cluster has a small affect towards decreasing FAR.
- POD remains about the same.
- POD increases with increasing scale size.

Constants:

- Algorithm spin-up time = 10 minutes
- Range limit = 120 km from LMA Center
- Forecast (warning) time: 45 minutes
- Flash rate threshold = 10
- Report cut off time after lightning data ends = 10 minutes
- 2 sigma jump algorithm

Constraints:

- Cell must exist in domain for >30 minutes
- Reports are not counted during cell spin up time.

SCALE VS. MAX REPORT DISTANCE FROM CLUSTER – LEAD TIME

Maximum Report Distance for Verification

Scale	5	10	15
1	21.62 ±13.0	22.15 ±12.7	21.85 ±12.6
2	23.08 ±12.5	22.96±12.3	22.38 ±12.4
3	22.04 ±12.4	21.9±12.5	21.94 ±12.6
4	22.38 ±12.9	22.16±12.7	22.18 ±12.8
5	23.61 ±12.8	23.78±12.9	23.79 ±12.7
6	22.25 ±12.5	22.5±12.5	22.14 ±12.6

Lead time between 21 and 23 minutes with a standard deviation of 12 .5 minutes.

Constants:

- Algorithm spin-up time = 10 minutes
- Range limit = 120 km from LMA Center
- Forecast (warning) time: 45 minutes
- Flash rate threshold = 10
- Report cut off time after lightning data ends = 10 minutes
- 2 sigma jump algorithm

Constraints:

- Cell must exist in domain for >30 minutes
- Reports are not counted during cell spin up time.

SCALE AND FLASH RATE THRESHOLD – POD:FAR

Minimum Flash Rate Threshold for Jump Occurrence

Scale	5	10	15	20
1	0.58 : 0.82	0.40 : 0.72	0.31 : 0.64	0.23 : 0.60
2	0.62 : 0.84	0.42 : 0.78	0.29 : 0.70	0.23 : 0.60
3	0.65 : 0.83	0.56 : 0.78	0.42 : 0.71	0.29 : 0.62
4	0.62 : 0.83	0.57 : 0.81	0.46 : 0.76	0.33 : 0.71
5	0.67 : 0.79	0.64 : 0.78	0.57 : 0.73	0.48 : 0.66
6	0.70 : 0.76	0.71 : 0.75	0.66 : 0.74	0.59 : 0.71

- POD increases at larger scale sizes.
- POD decreases with increasing flash rate threshold.
- FAR decreases with increasing flash rate threshold.

Constants:

- Algorithm spin-up time = 12 minutes
- Range limit = 120 km from LMA Center
- Forecast (warning) time: 45 minutes
- Report cut off time after lightning data ends = 10 minutes
- Report distance from feature = 10 km
- 2 sigma jump algorithm

Constraints:

- Cell must exist in domain for >30 minutes
- Reports are not counted during cell spin up time.

SCALE AND FLASH RATE THRESHOLD – LEAD TIME

Minimum Flash Rate Threshold for Jump Occurrence

Scale	5	10	15	20
1	22.38 ±12.6	22.15 ±12.7	21.64 ±12.8	21.18 ±12.7
2	22.75 ±12.5	22.96 ±12.3	22.33 ±12.3	21.64 ±12.3
3	22.19 ±12.6	21.9 ±12.5	21.23 ±12.6	20.84 ±12.9
4	21.94 ±12.9	22.16 ±12.7	22.15 ±12.4	22.23 ±12.6
5	23.42 ±12.9	23.78 ±12.9	23.87 ±12.7	23.37 ±12.9
6	22.55 ±12.6	22.5 ±12.5	22.86 ±12.5	22.14 ±12.6

Lead time between 21 and 23 minutes with a standard deviation of 12 minutes.

Constants:

- Algorithm spin-up time = 12 minutes
- Range limit = 120 km from LMA Center
- Forecast (warning) time: 45 minutes
- Report cut off time after lightning data ends = 10 minutes
- Report distance from feature = 10 km
- 2 sigma jump algorithm

Constraints:

- Cell must exist in domain for >30 minutes
- Reports are not counted during cell spin up time.

SUMMARY AND CONCLUSIONS

- This study assessed the LJA using the GLM Proxy data set and automated, objective cell tracking techniques.
  - Explored the affect of tracked scale size, storm report location associated to tracked cluster and lightning flash rate threshold for the LJA.
- THIS STUDY: For larger tracked scales, POD (0.6 – 0.7) and lead time (21-23 ±12 minutes) similar to recent Schultz et al. but FAR is noticeably higher (0.7 – 0.8)
- Update to Schultz et al. (2011) database:
  - 1290 cells (405 severe, 885 non severe), 1368 reports
  - 65% POD, 46% FAR
  - lead time 27 ±12 minutes
- Hypotheses for differences between the two studies:
  - Automated and objective WDSSII tracking (this study) vs. subjective corrections to TITAN tracks (Schultz et al. 2011)
  - Some differences in lightning flash rates: native LMA vs. GLM proxy
  - Storm sample: Ratio of severe to non severe storms (at smaller scales for tracking)

ONGOING AND FUTURE WORK

- Total lightning and dual-polarization radar data fusion for severe weather situational awareness
  - Tornado: environment + total flash rate + LJA + Doppler mesocyclone/rotation + dual-polarization
  - Hail: environment + LJA + MESH/dual-polarization
- NWS forecaster feedback on LJA performance, visualization and best practices in nowcasting
  - NASA SPoRT
- Continued refinement and improvement of the LJA algorithm, including tracking optimization

EXTRA SLIDES

CELL TRACKING

Track values where VILFRD ≥ 20, using increments of 20, with anything over 100 set to 100.

Tracker (**WDSSII *w2segmotionll***) builds cells until a minimum size threshold is met. Several size scales tested ranging from ~30 to ~300 km^2.

First see if values exceeding 100 cover large enough area (e.g., cells 26, 42, 72, 83)

If not, include values exceeding 80 (e.g., cells 66, 89), and so on for decreasing values of 60, 40, and 20.

Tracking uses **maximum overlap** approach for associating cells from one time step to the next.

Cells are projected forward from time *t* to *t+1* (1-minute increments, so projected motion has very little effect)

If an observed cell at *t+1* matches a cell location projected forward from *t*, within (5 km) or (1 x Size of Cell), then it is associated with that previously identified cell's history.

If a cell disappears in one time step, it cannot re-appear later.

Outside WDSSII, "broken tracks" are objectively merged. If WDSSII has a new cell begin at *t+1* within 15 km of where a previous cell track ended at time *t*, those cell histories are tied together.

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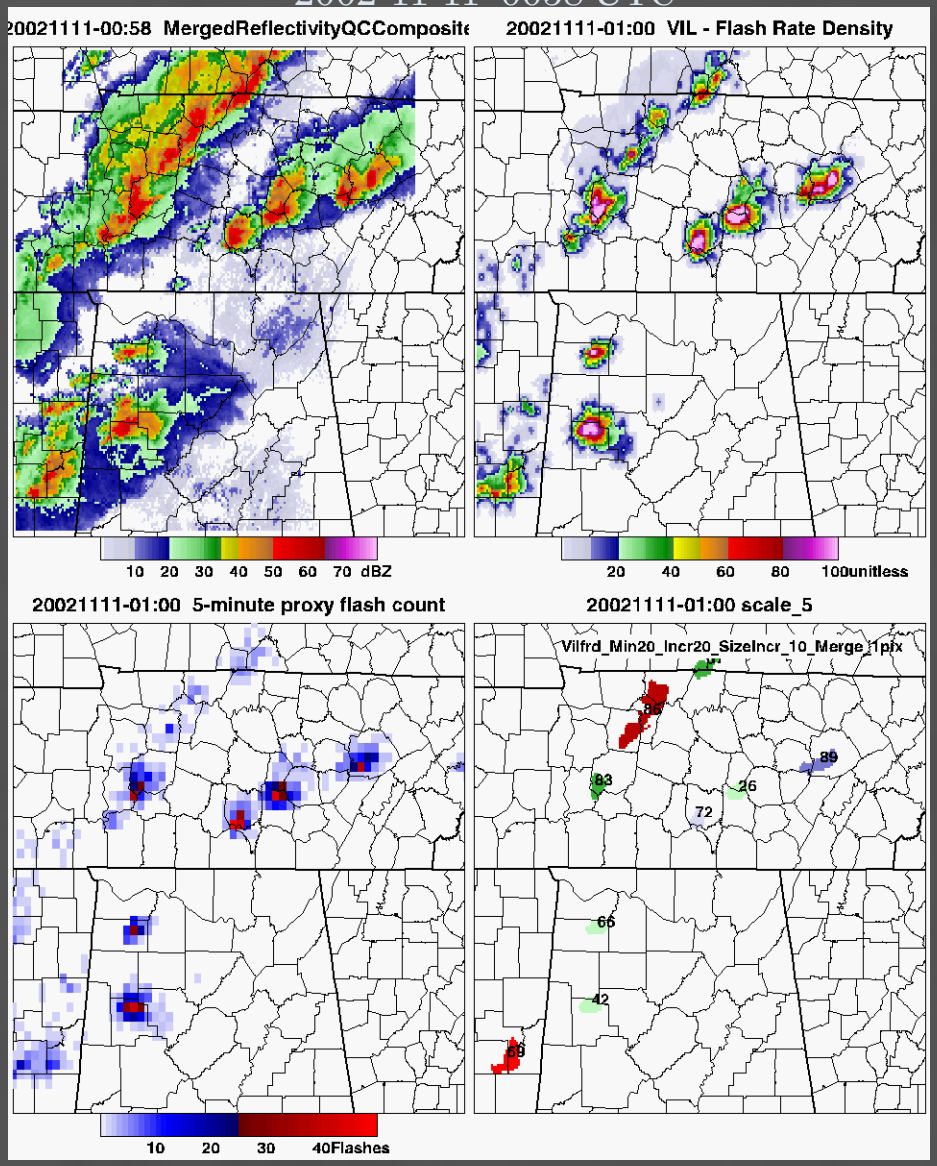

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$$VILFRD = 100 * (((VIL/45) \leq 1) + (sqrt(Flct5/45) \leq 1))$$

REPORT ASSOCIATION AND VERIFICATION RULES

Based on Schultz et al. 2009 and 2011

- Jumps within 6 minutes of each other are only 1 jump
- All reports are grouped every 6 minutes starting from initial report time associated with cell
- Reports are associated within a WDSSII tracked cluster or within X distance of the cluster
- Reports can only confirm one forecast/warning.
- Each report (after grouping) that occurs within a forecast period is considered a hit.
- When subsequent jump occurs during a forecast, only the time after the first forecast is expired is the subsequent forecast (jump/warning) allowed to be verified. Otherwise it is a false alarm.
- Forecast/warning time is currently set at 45 minutes