

Intercomparison of Lightning Measurements in Tornadic QLCS Storms

How Different Lightning Networks Behave Surrounding Tornadoes



Authors: Jacquelyn Ringhausen^{1,2,3}, Vanna Chmielewski¹, Kristin Calhoun¹

¹NOAA / OAR National Severe Storms Laboratory

²Cooperative Institute for Severe and High-Impact Weather Research and Operations

³University of Oklahoma

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Contact email: jacquelyn.ringhausen@noaa.gov

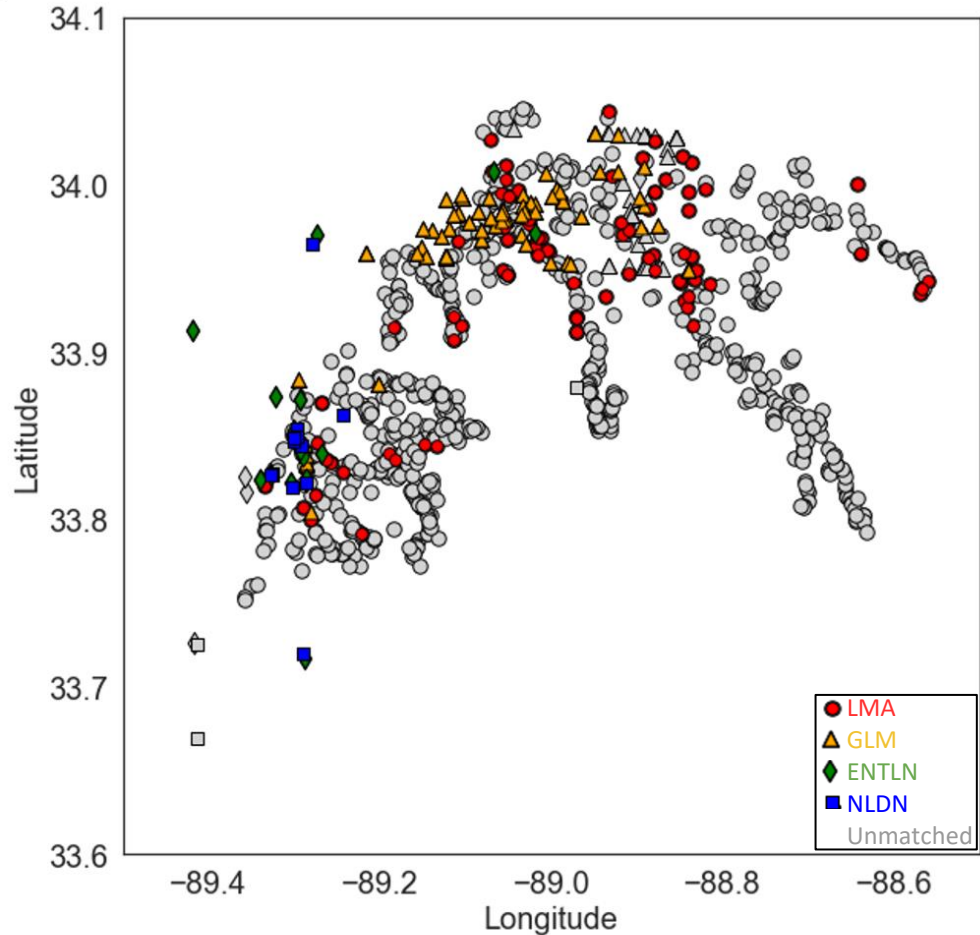
Motivation

Lightning location networks differ in their methods of lightning detection based on:

- network detection efficiency
- flash sorting algorithms
- methods of detection

Due to these differences, each network can provide unique information about not only the lightning occurring, but their contrast can imply something about the meteorological environment.

Thus, combining networks provides more information than any single network can alone.



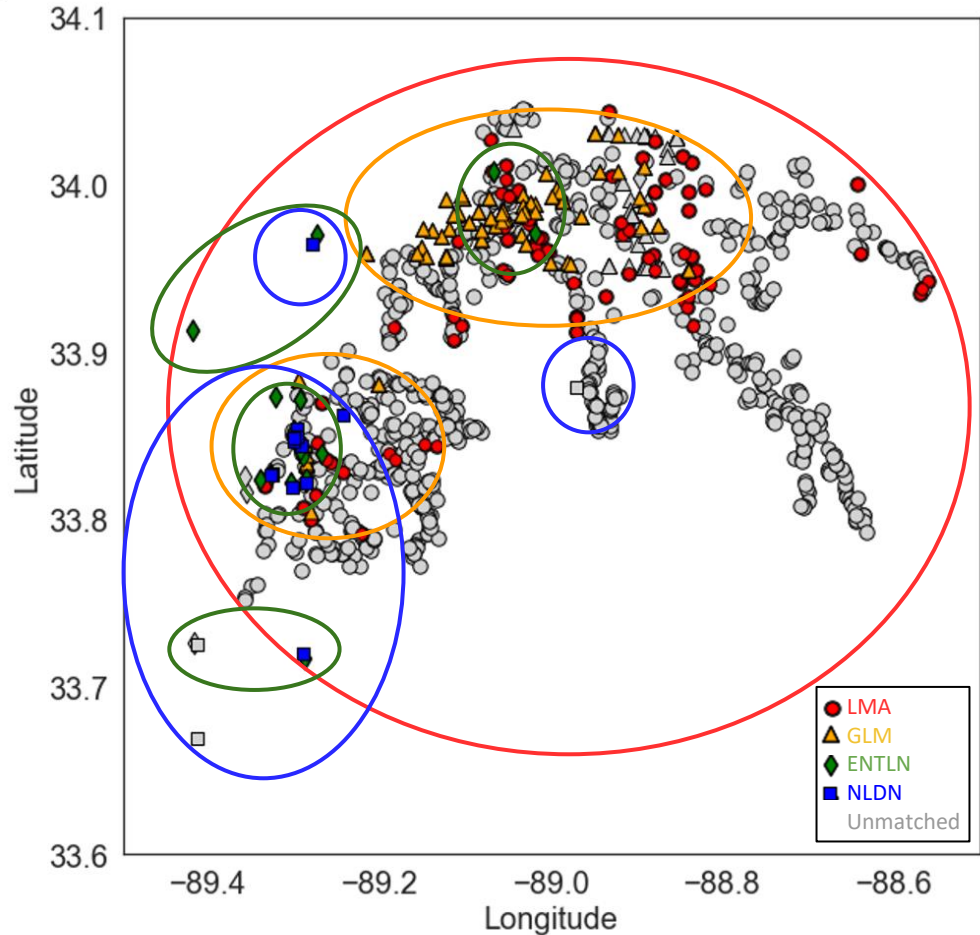
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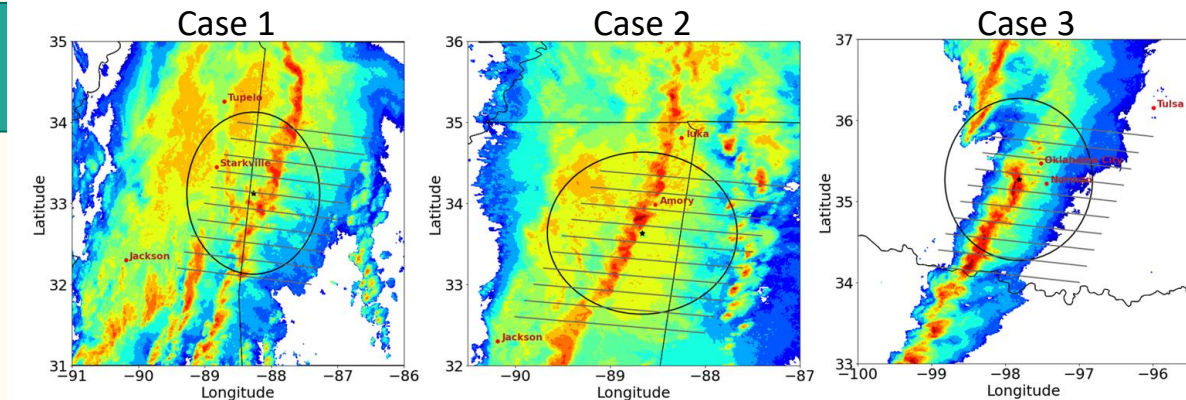
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Data

Want to compare how lightning networks behave during tornadoes



4 Lightning Networks:

- Lightning Mapping Array (LMA)
- Earth Networks Total Lightning Network (ENTLN)
- National Lightning Detection Network (NLDN)
- Geostationary Lightning Mapper (GLM)

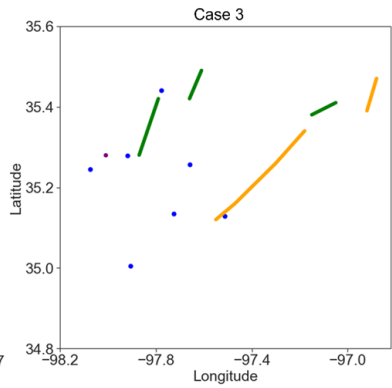
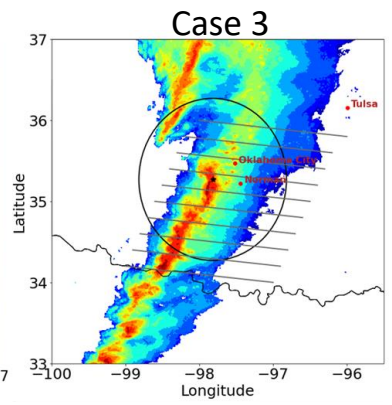
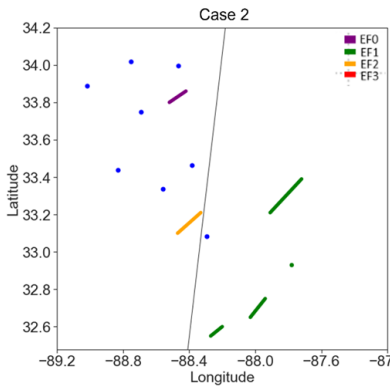
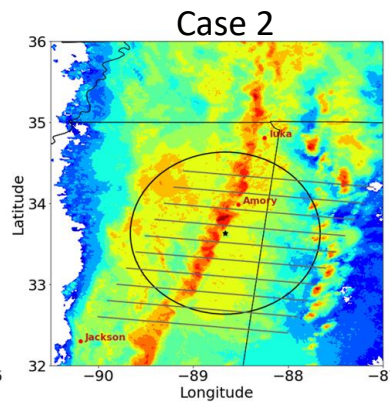
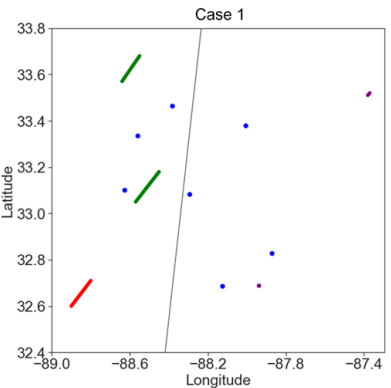
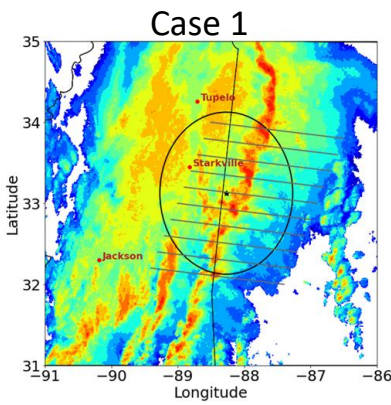
3 QLCSs:

- Case 1: IOP1 March 22, 2022
- Case 2: IOP2 March 30, 2022
- Case 3: OK February 26, 2023

		Case 1	Case 2	Case 3
Date		3/22/22	3/30/22 – 3/31/22	2/27/23
Time		1800 – 2359 UTC	2100 – 0300 UTC	0100 – 0400 UTC
Latitude Range		31.0 to 35.1	31.0 to 36.0	32.0 to 37.0
Longitude Range		-90.6 to -86.1	-90.0 to -87.0	-100.0 to -95.5
<i>LMA</i>	Total	78816	75710	40869
<i>GLM</i>	Total	44054	36076	24432
	Total	71321	59635	30976
<i>ENTLN</i>	IC	50076	45778	27052
	CG	21245	13857	8441
	Total	46831	32676	26953
<i>NLDN</i>	IC	36617	26645	23029
	CG	10214	6031	3924

Data

Date	Time (UTC)	EF Rating	Location	lat/lon
3/22/22	1935 – 1946	EF3	Martin, MS	32.60, -88.90
3/22/22	2004 – 2020	EF1	Westpoint, MS	33.57, -88.64
3/22/22	2016 – 2034	EF1	Shuqualak, MS	33.05, -88.57
3/22/22	2300 – 2302	EF0	Thornhill, AL	32.69, -87.94
3/22/22	2321 – 2325	EF0	Bankhead, AL	33.51, -87.38
<hr/>				
3/31/22	0016 – 0026	EF0	Aberdeen, MS	33.80, -88.52
3/31/22	0108 – 0120	EF2	Macon, MS	33.10, -88.47
3/31/22	0151 – 0202	EF1	Livingston, AL	32.55, -89.27
3/31/22	0202 – 0221	EF1	Kirk, AL	33.21, -87.91
3/31/22	0210 – 0221	EF1	Burton Hill, AL	32.65, -88.03
3/31/22	0238 – 0240	EF1	Akron, AL	32.93, -87.78
<hr/>				
2/27/23	0252 – 0253	EF0	Minco, OK	35.28, -98.01
2/27/23	0257 – 0307	EF1	Mustang, OK	35.28, -97.87
2/27/23	0309 – 0335	EF2	Norman, OK	35.12, -97.55
2/27/23	0312 – 0318	EF1	Oklahoma City, OK	35.42, -97.66
2/27/23	0342 – 0348	EF1	Dale, OK	35.38, -97.15
2/27/23	0345 – 0351	EF2	Shawnee, OK	35.39, -96.92



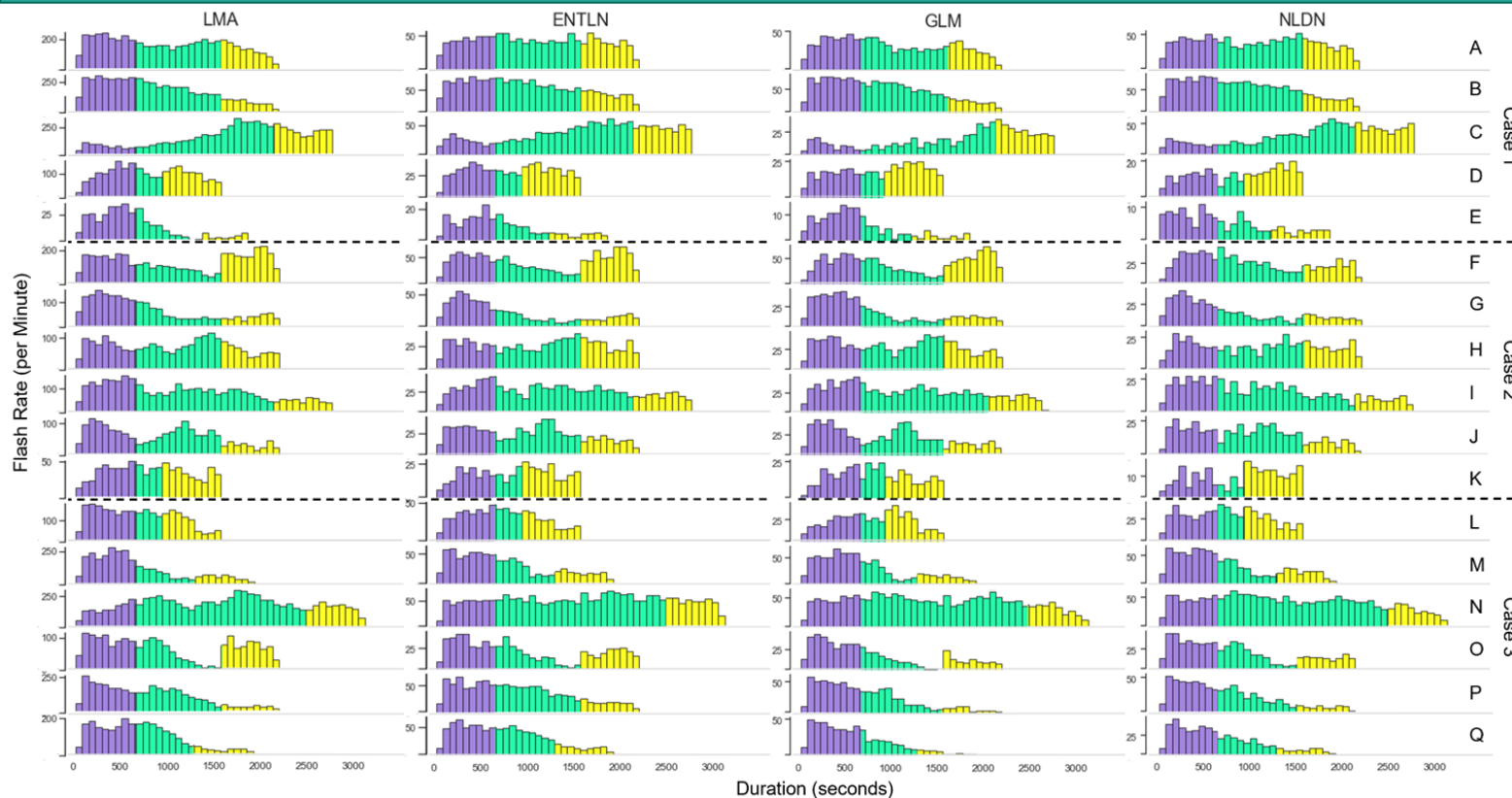
17 Tornadoes:

- Tracked ten minutes prior, tornado duration, and ten minutes following, radius of 25 km

- tornadoes provide a clear signature/reference point for analysis, which may be tied to updraft variations

Flash Rates

■ Before Tornado
■ During Tornado
■ Following Tornado



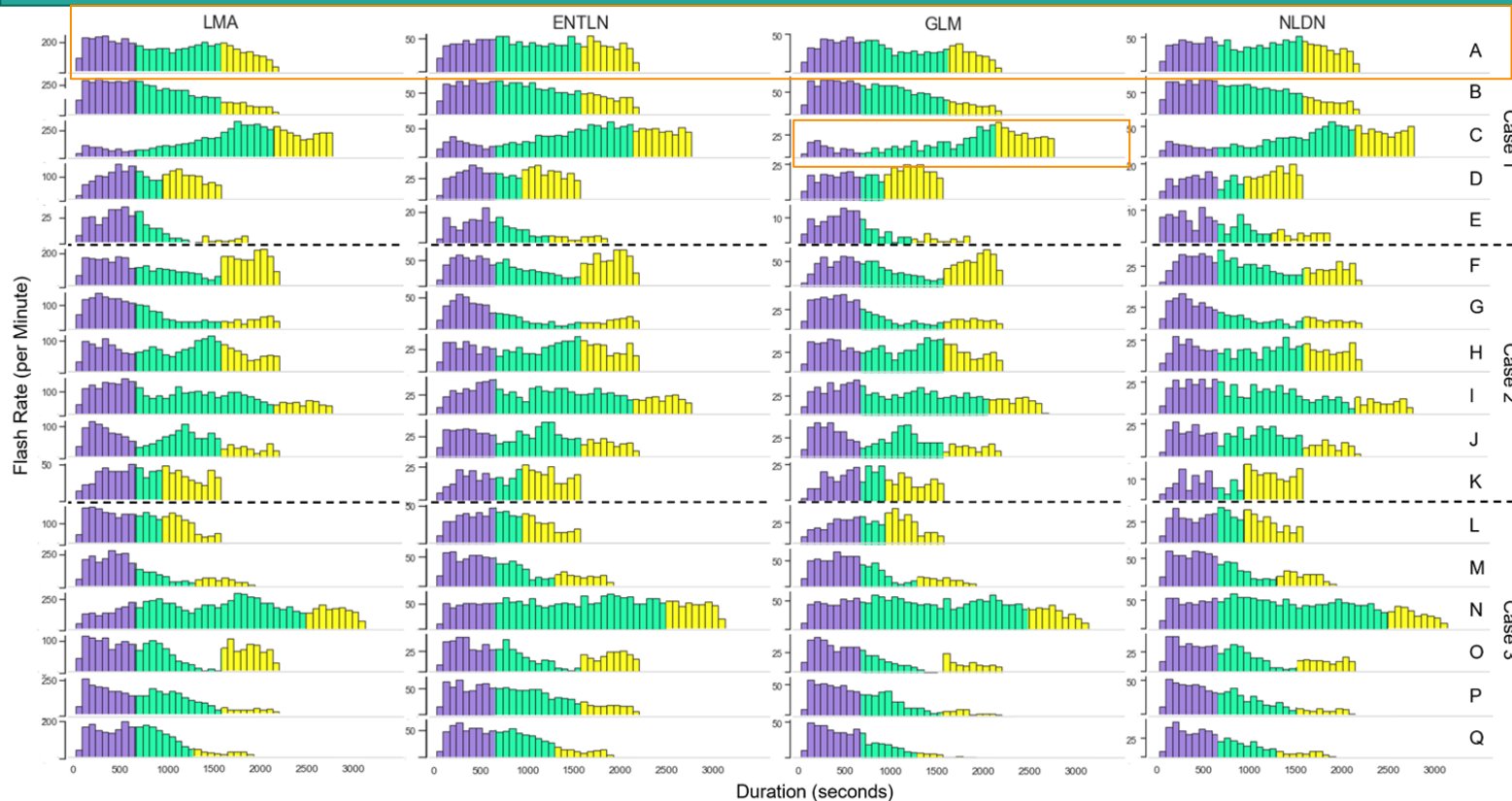
—Most of the flash rate trends between networks are overall similar in appearance, different in magnitudes

—Often see a local maximum in flash rate prior to tornado, then a decrease in flash rate during the tornado

*Tornado C is an exception to this

Flash Rates

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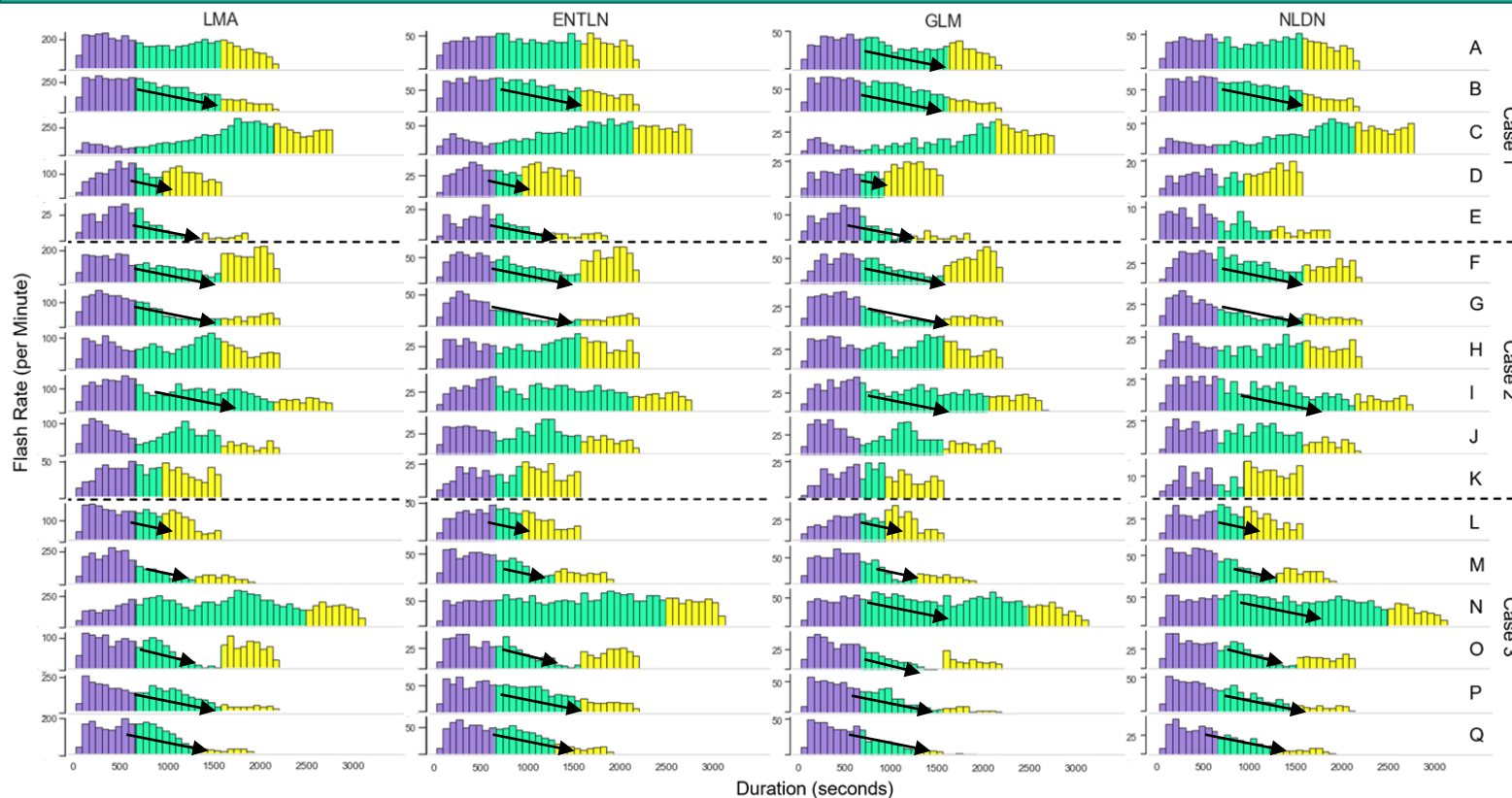
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10/17 negatively correlated

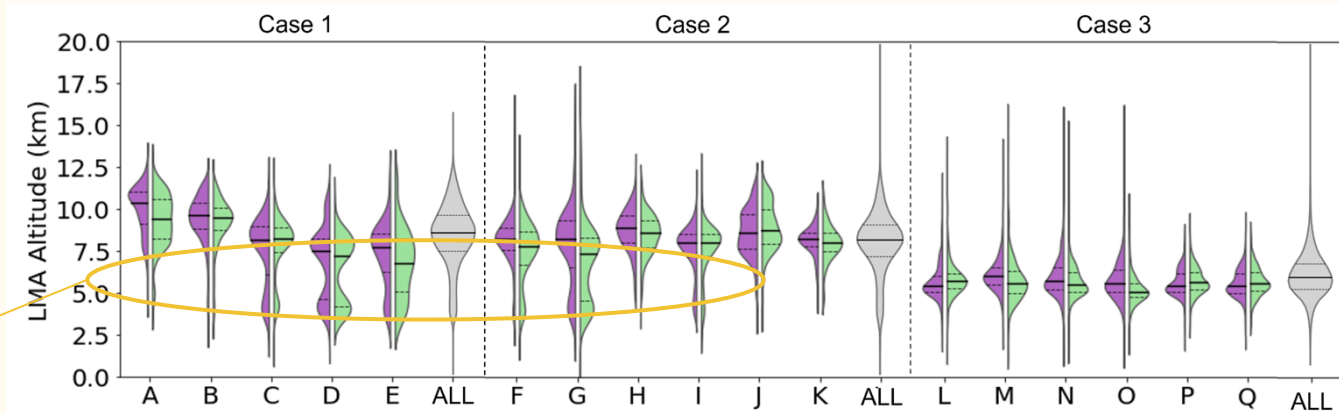
9/17 negatively correlated

13/17 negatively correlated

10/17 negatively correlated

Initiation Altitude Changes Surrounding Tornadoes

A more prominent lower altitude initiation region occurs during many tornadoes versus the overall QLCS.



Higher flash initiations occur just prior to tornadoes versus the overall QLCS.

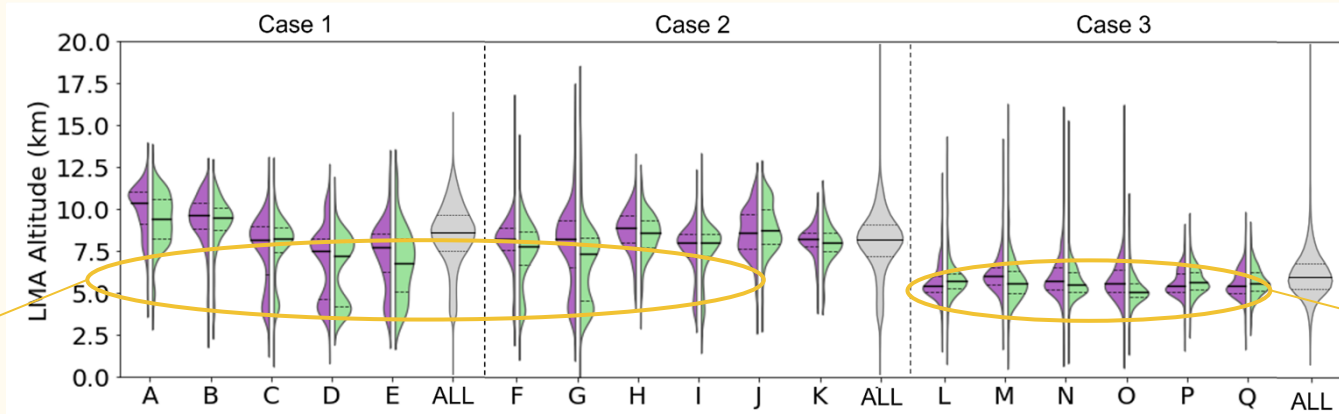
	CASE 1	CASE 2	CASE 3
	LMA Altitude (km)	LMA Altitude (km)	LMA Altitude (km)
Before Tornado	9.0/ 9.3	8.1/8.3	5.9/5.8
During Tornado	8.5/8.7	7.9/8.1	5.7/5.6
Overall QLCS	8.4/8.6	7.7/7.9	6.1/6.0

10 Minutes before Tornado
Overall QLCS

During Tornado

Initiation Altitude Changes Surrounding Tornadoes

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Case three has only the lower altitude region during tornadoes

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Overall QLCS

During Tornado

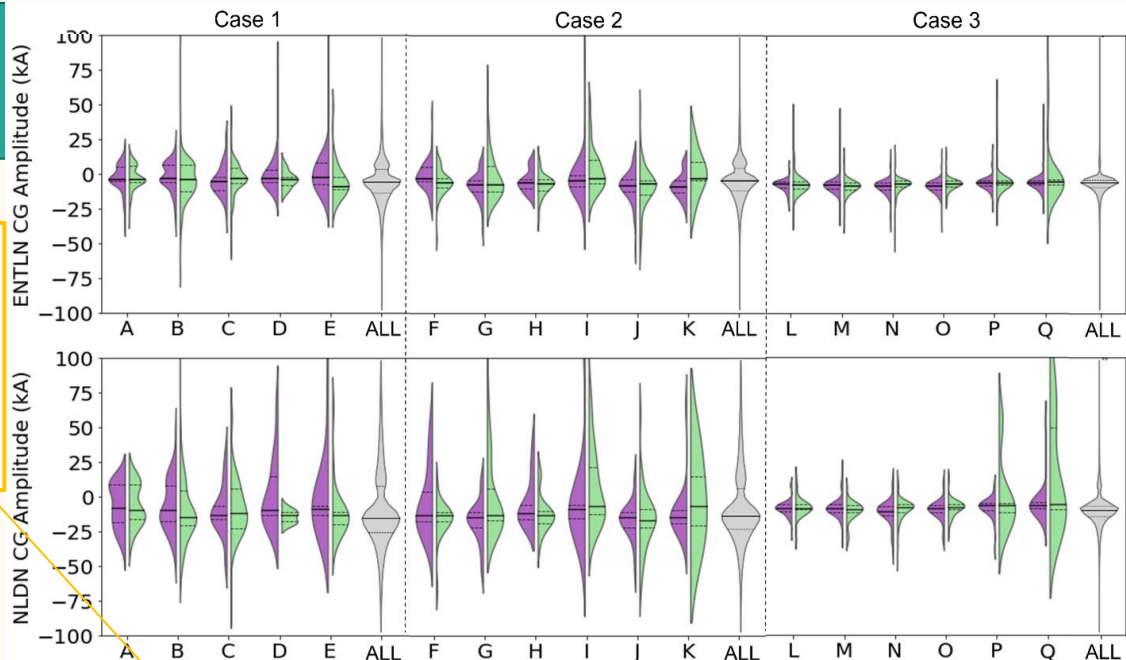
Flash Type: CG

Case 1 and Case 2:

- CG flashes surrounding tornadoes are lower energy (both - and +) on average than the overall QLCS.
- NLDN CG flashes are higher energy than ENTLN CGs.

Case 3:

- Smaller amplitudes overall than Case 1 and 2
- Positive CG flashes have higher energy on average during tornadoes than prior to tornado or the overall QLCS
- NLDN and ENTLN CG amplitudes are more similar than other cases



	Case 1				Case 2				Case 3			
	ENTLN		NLDN		ENTLN		NLDN		ENTLN		NLDN	
	+	-	+	-	+	-	+	-	+	-	+	-
Before Tornado	9.7	-8.1	18.8	-16.6	10.2	-10.1	28.5	-19.3	12.5	-8.5	11.2	-10.4
During Tornado	9.0	-9.6	17.8	-19.1	15.1	-9.9	28.6	-17.5	21.5	-8.1	28.7	-10.4
Overall QLCS	15.7	-12.3	32.0	-23.3	15.7	-11.9	31.2	-21.9	15.7	-9.1	17.7	-12.1

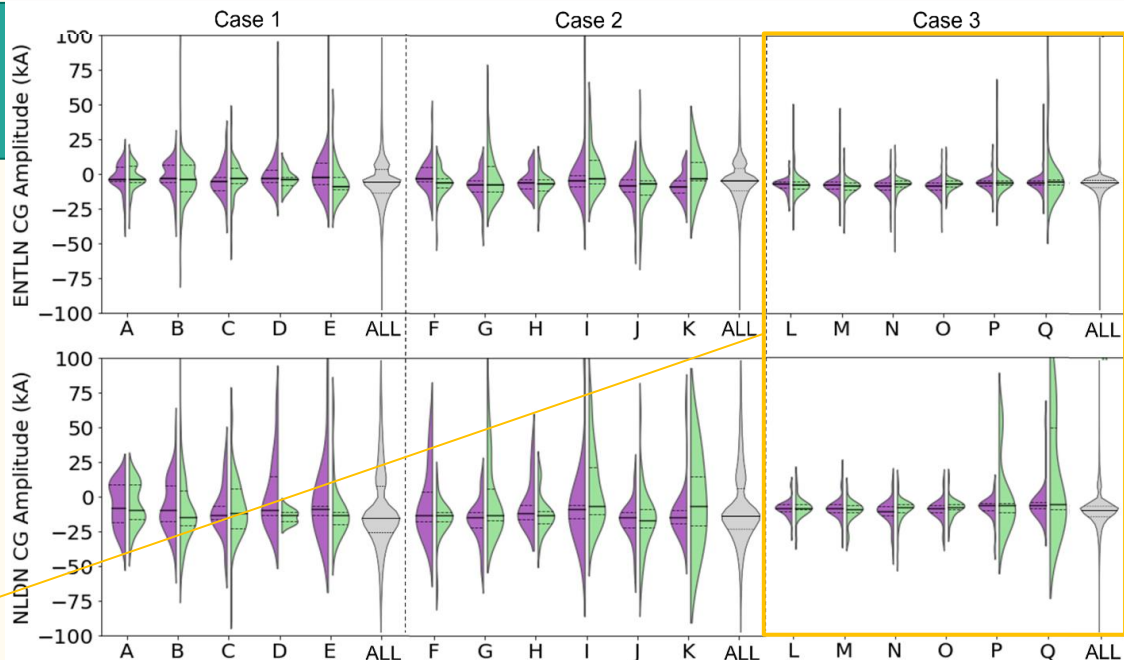
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	ENTLN		NLDN		ENTLN		NLDN		ENTLN		NLDN	
	+	-	+	-	+	-	+	-	+	-	+	-
Before Tornado	9.7	-8.1	18.8	-16.6	10.2	-10.1	28.5	-19.3	12.5	-8.5	11.2	-10.4
During Tornado	9.0	-9.6	17.8	-19.1	15.1	-9.9	28.6	-17.5	21.5	-8.1	28.7	-10.4
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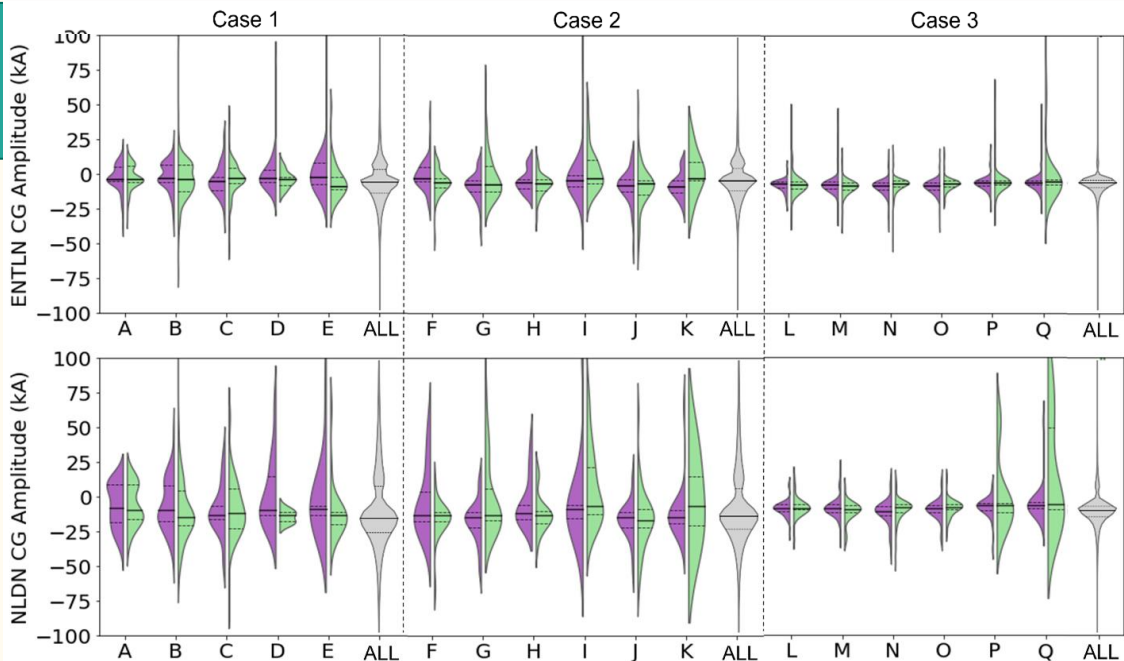
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	+	-	+	-	+	-	+	-	+	-	+	-
Before Tornado	9.7	-8.1	18.8	-16.6	10.2	-10.1	28.5	-19.3	12.5	-8.5	11.2	-10.4
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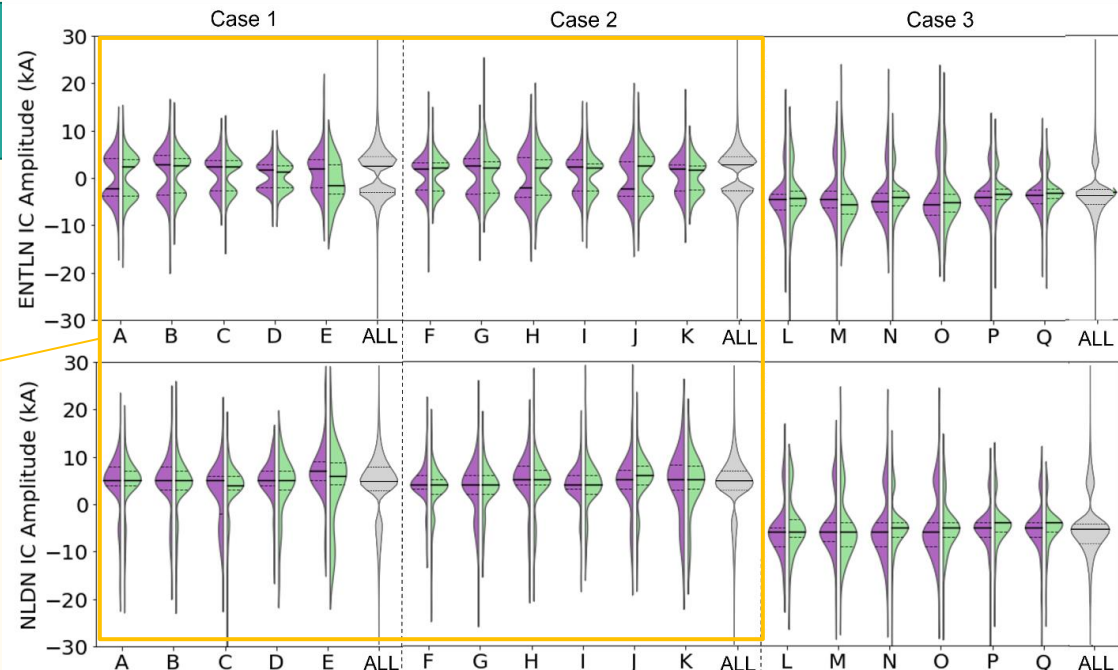
Flash Type: IC

Case 1 and Case 2:

- For ICs, most are positive for NLDN, equal negative and positive for ENTNLN
- Not much difference in IC amplitudes surrounding tornadoes versus the overall QLCS

Case 3:

- Very few positive flashes in general
- NLDN and ENTNLN more in alignment for this case
- Not much difference in IC amplitudes surrounding tornadoes versus the overall QLCS



	Case1				Case 2				Case 3			
	ENTNLN		NLDN		ENTNLN		NLDN		ENTNLN		NLDN	
	+	-	+	-	+	-	+	-	+	-	+	-
Before Tornado	4.2	-3.8	6.4	-7.2	4.0	-3.9	5.9	-6.5	5.6	-5.4	5.9	-7.1
During Tornado	3.9	-3.8	5.8	-6.9	3.9	-3.8	5.7	-6.0	4.6	-4.9	5.3	-6.4
Overall QLCS	4.6	-4.1	6.8	-7.7	4.3	-4.0	6.4	-7.3	4.9	-5.1	5.9	-6.9

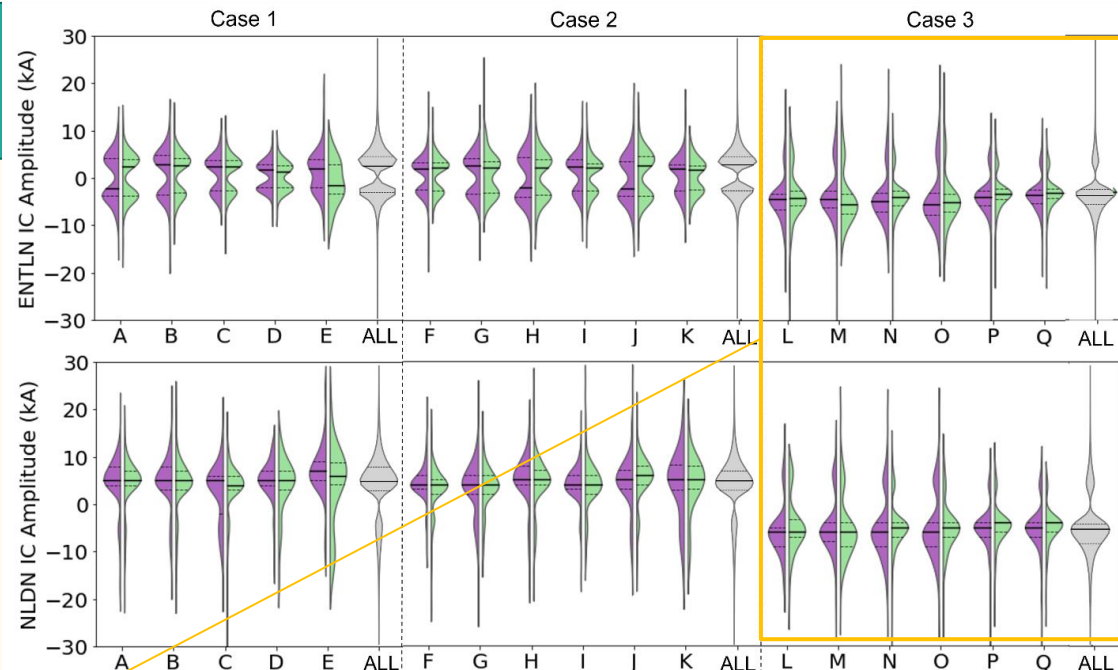
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Before Tornado	4.2	-3.8	6.4	-7.2	4.0	-3.9	5.9	-6.5	5.6	-5.4	5.9	-7.1
During Tornado	3.9	-3.8	5.8	-6.9	3.9	-3.8	5.7	-6.0	4.6	-4.9	5.3	-6.4
Overall QLCS	4.6	-4.1	6.8	-7.7	4.3	-4.0	6.4	-7.3	4.9	-5.1	5.9	-6.9

Cloud Flash Fraction

- For Case 1 and 2, CFF is larger during tornadoes than the overall QLCS for both ENTLN and NLDN, implying more IC flashes occur surrounding tornadoes
- For Case 3, ENTLN has a larger fraction of CGs surrounding tornadoes than the overall QLCS
 - NLDN does not show this pattern

	Case 1			Case 2			Case 3		
	IC	CG	CFF	IC	CG	CFF	IC	CG	CFF
ENTLN	3124	1031	0.752	3185	570	0.848	4079	1788	0.695
NLDN	3065	403	0.884	2214	267	0.892	3764	622	0.858
Overall ENTLN	50076	21245	0.702	45778	13857	0.768	27052	8441	0.762
Overall NLDN	43812	10875	0.787	35085	7566	0.823	24762	4236	0.854

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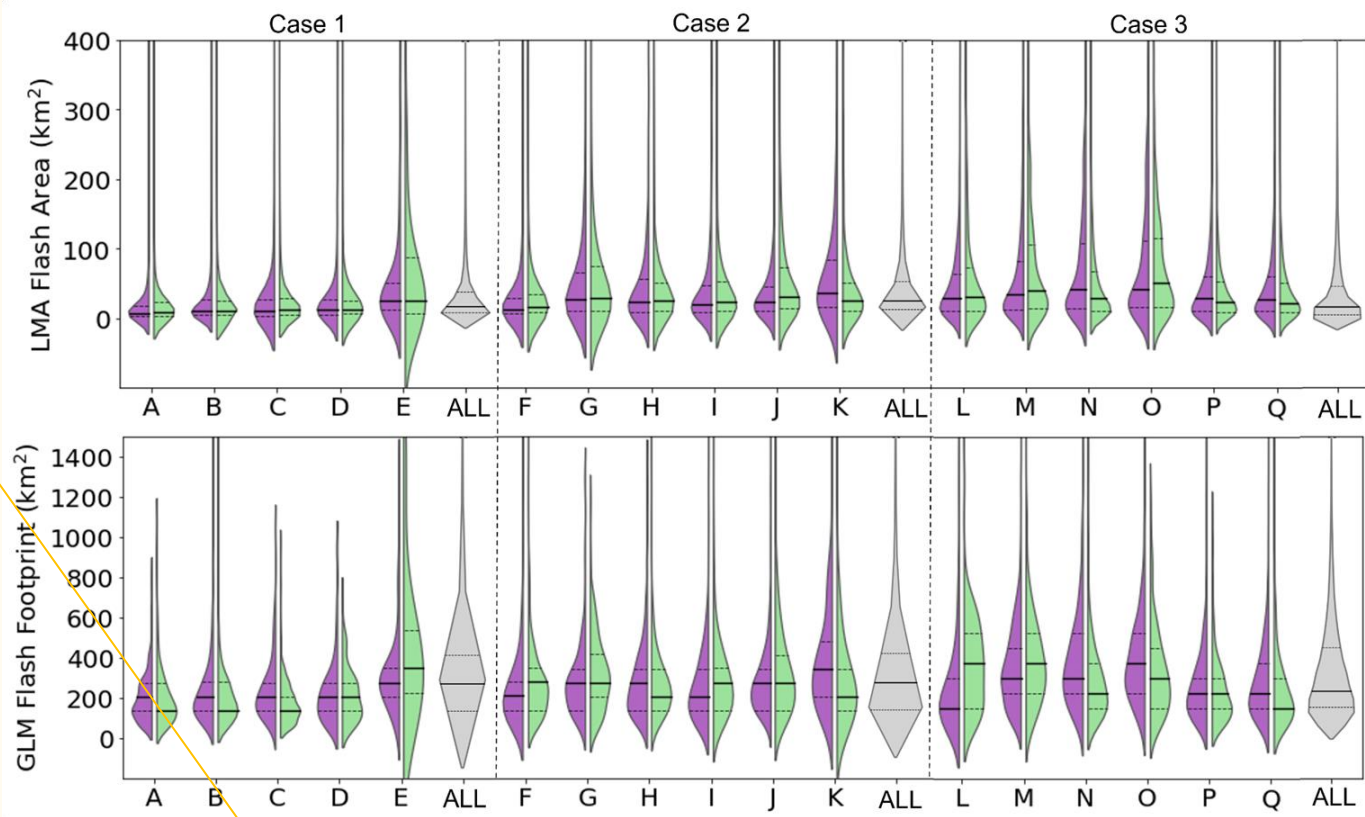
Flash Size

Case 1 and Case 2:

- Average GLM and LMA area are smaller surrounding tornadoes than the overall QLCS, especially GLM

Case 3:

- LMA flashes are larger during tornadoes versus overall QLCS
 - GLM did not follow the same pattern



	CASE 1		CASE 2		CASE 3	
	LMA Area	GLM Footprint	LMA Area	GLM Footprint	LMA Area	GLM Footprint
Before Tornado	34.9/14.4	273.8/209.2	45.9/20.2	296.7/274.1	74.1/44.7	327.3/298.8
During Tornado	29.3/11.7	254.7/207.8	49.6/20.6	319.5/275.8	62.8/37.5	304.5/224.6
Overall QLCS	45.7/17.5	464.1/276.5	50.2/22.2	477.2/279.4	48.1/23.2	332.9/229.2

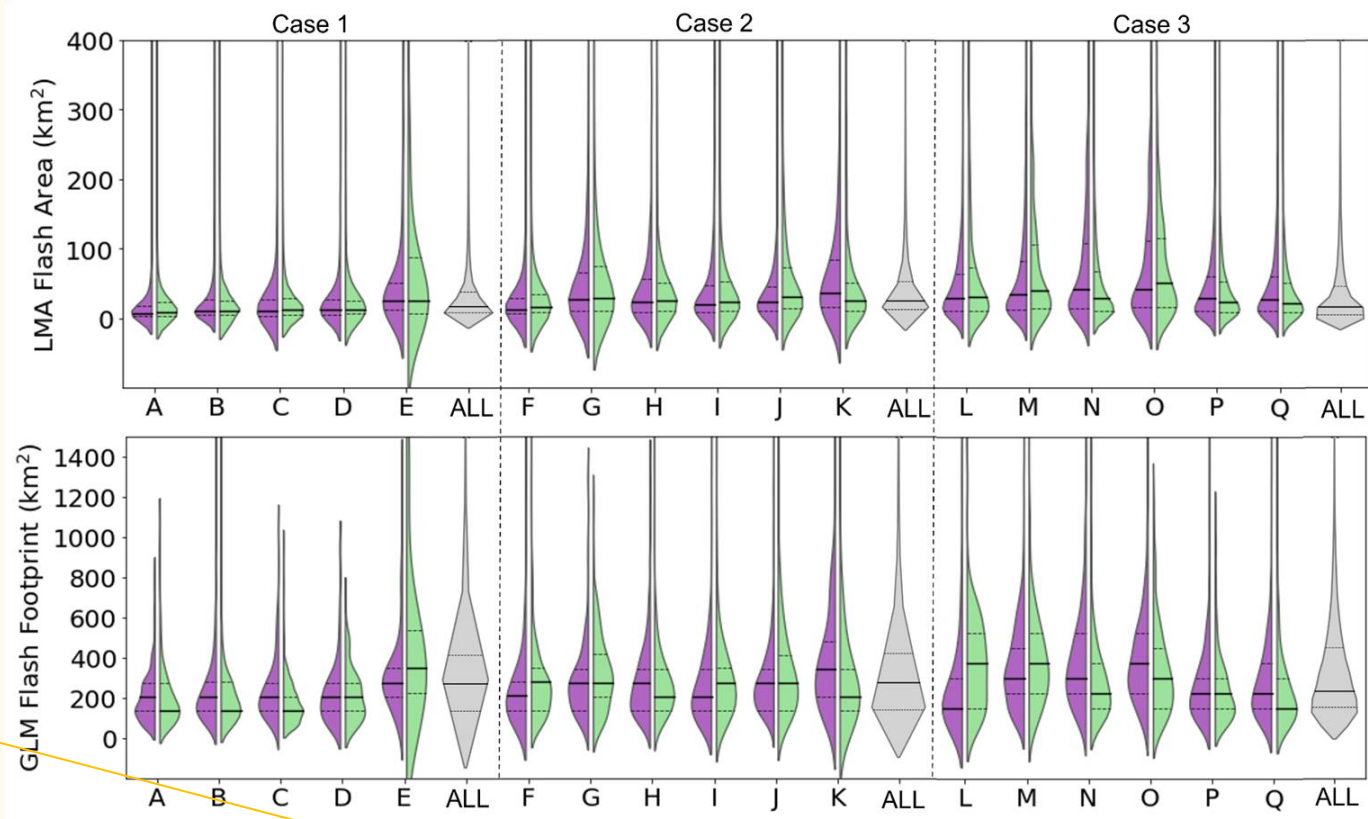
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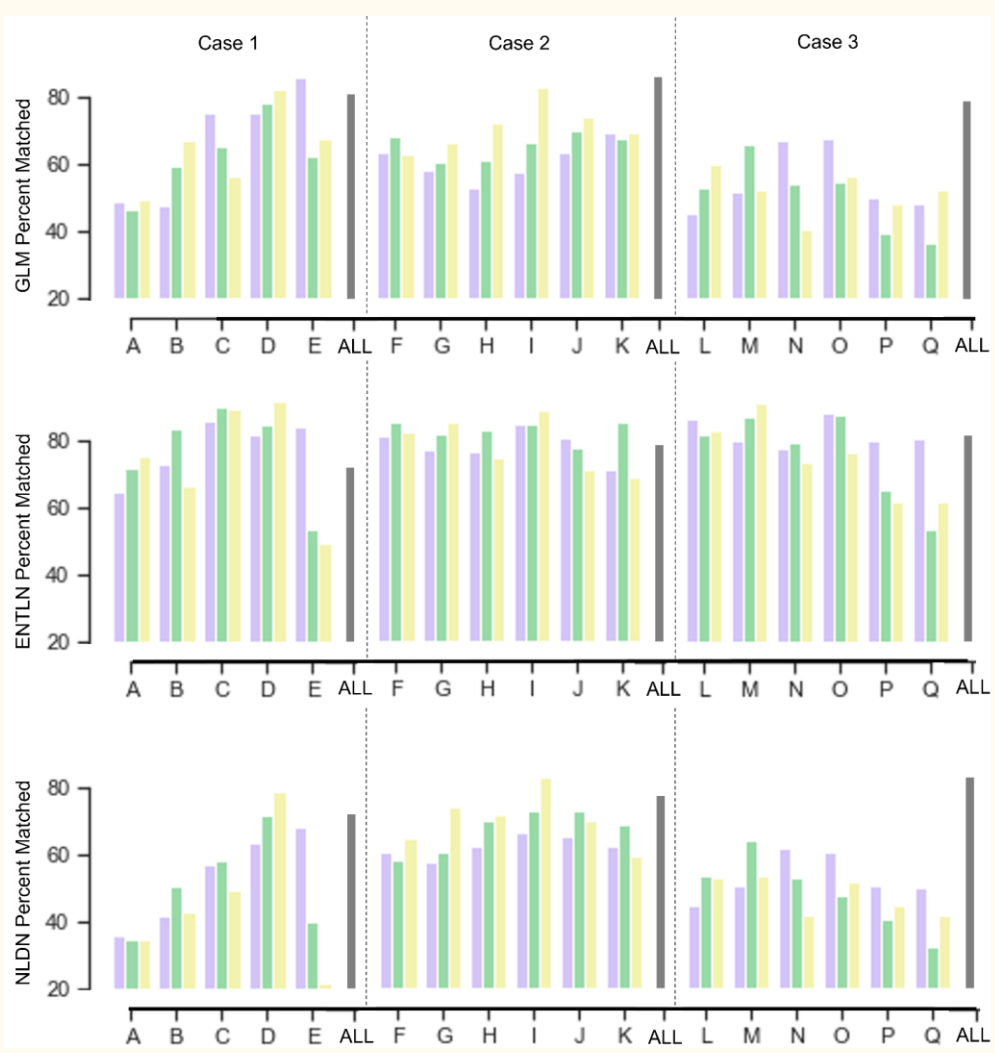


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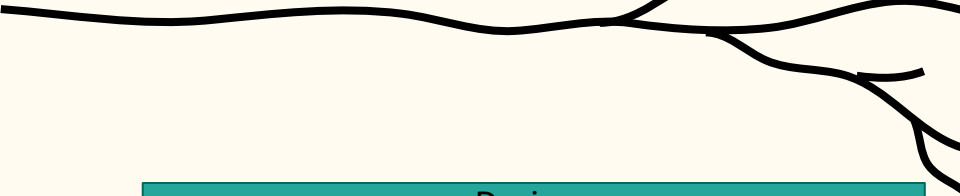
Percent Matched

- Before Tornado
- During Tornado
- Following Tornado
- Overall QLCS

- For GLM and NLDN, the percentage of flashes that matched to LMA surrounding tornadoes were lower than the overall QLCS for all cases.
 - Lowest percent matched for Case 3
- For ENTLN, percentages matched were similar to overall QLCS
- Case 1 and 2 had less flashes matching just prior to tornadoes and decreased during tornadoes, while Case 3 had the opposite



Summary



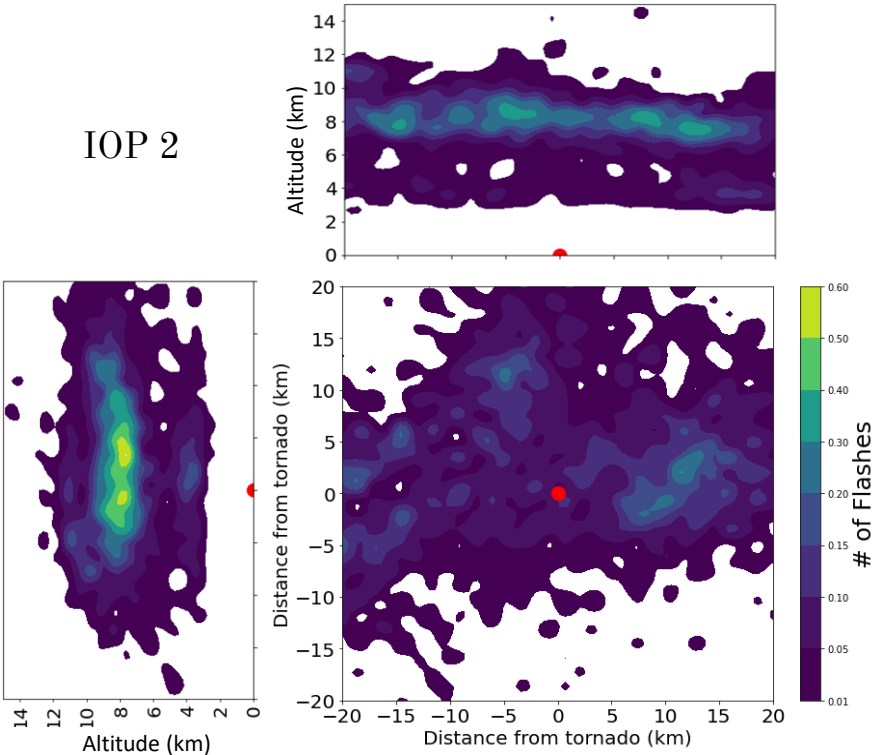
	During Tornadoes		
	← INCREASES		→ DECREASES
LMA	Normal	Altitude	Size, Amount, Matching
	Anomalous	Size	Altitude, Amount, Matching
GLM	Normal		Size, Energy, Amount, Matching
	Anomalous		Energy, Amount, Matching
ENTLN	Normal	IC flashes	Energy, Amount
	Anomalous	CG flashes, Energy	Amount
NLDN	Normal	IC flashes	Energy, Amount, Matching
	Anomalous		Amount, Matching

- ❑ Comparing network trends surrounding tornadoes, it is evident that there are differences in both detection and classification of lightning depending on the network
- ❑ Periods just prior to tornadoes tended to be associated with localized increases in lightning, ICs, and higher altitude flashes, while decreases in flash rates, smaller flashes, and a lower altitude region of lightning occurred during tornadoes
 - Anomalous storm was somewhat different
- ❑ Flashes were more likely to be detected by all 4 networks in areas of lower flash rates, larger flashes, and less ICs, and matched less during tornadoes than the overall QLCS
- ❑ **Future work:**
 - Analyze more cases to see if trends hold, and link more of the microphysics to each network's performance.
 - Create a merged product

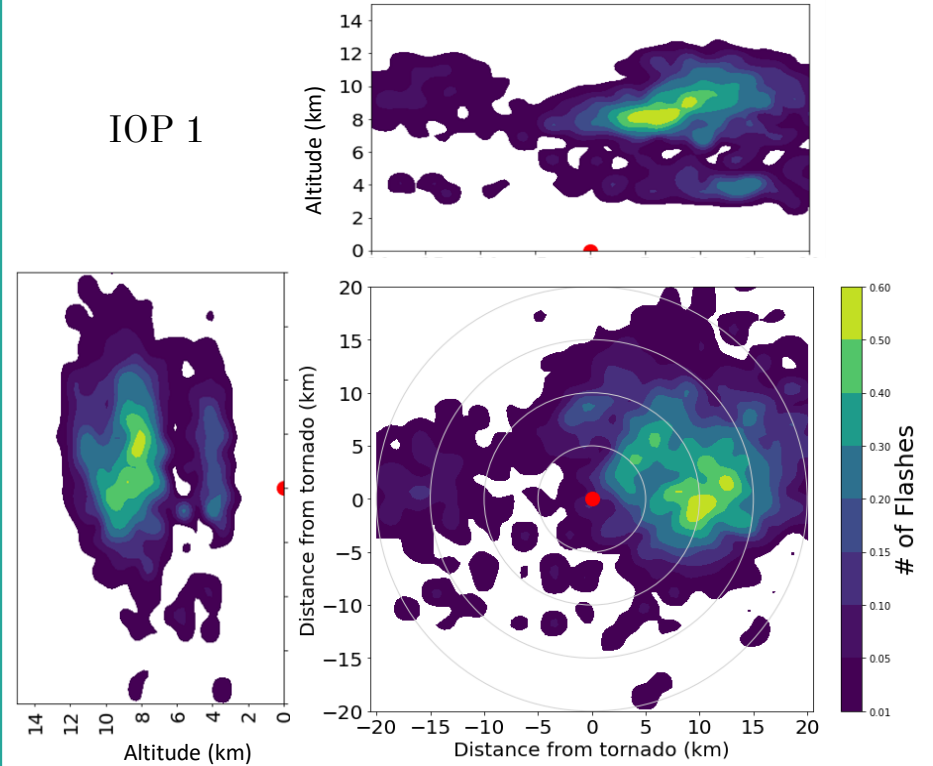
Lightning Locations

- Both IOP1 and IOP2 display more lightning to the north of the tornado and two regions of initiation

IOP 2

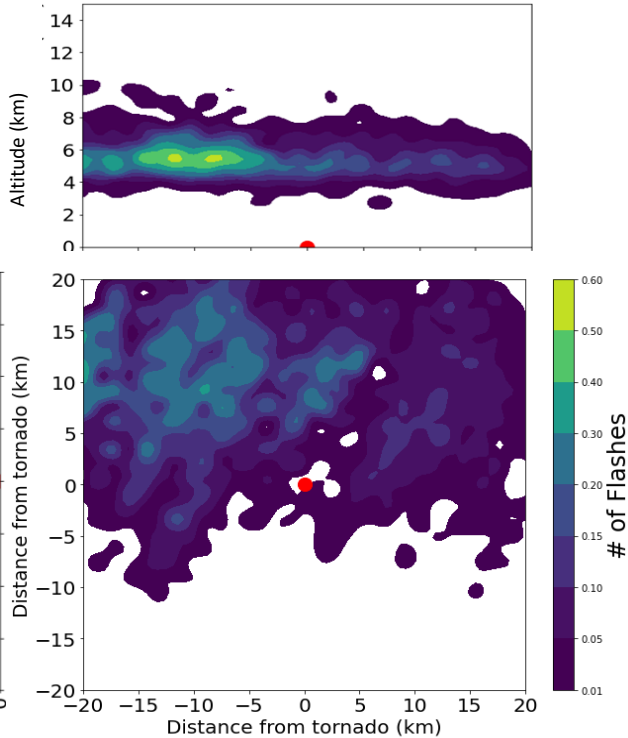


IOP 1



Lightning Locations

IOP 3

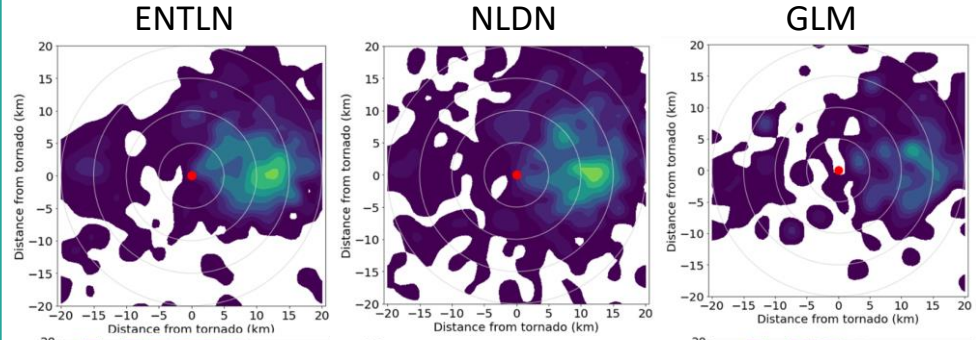


- Similar to IOP 1 and 2, most of lightning north of tornado in IOP3
 - Further west
- IOP3 had only one main region of flash initiation

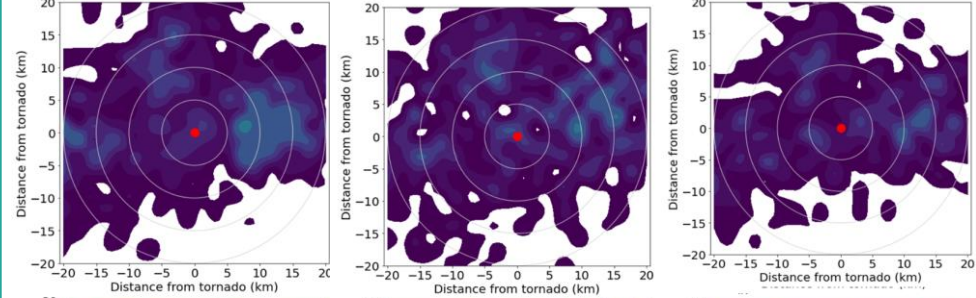
Spatial Plots

- Show similar spatial patterns of lightning as LMA, with maximum to the east of tornado and less lightning to the south

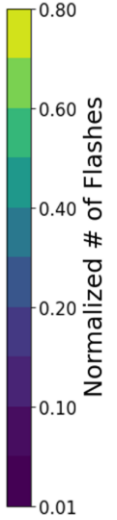
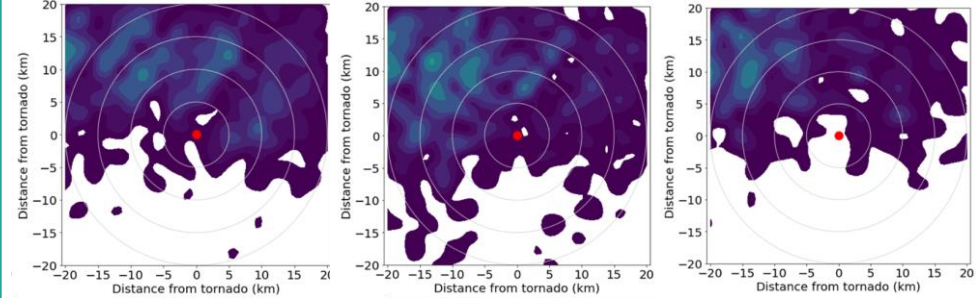
Case 1



Case 2



Case 3



Lightning Characteristics during Tornadoes

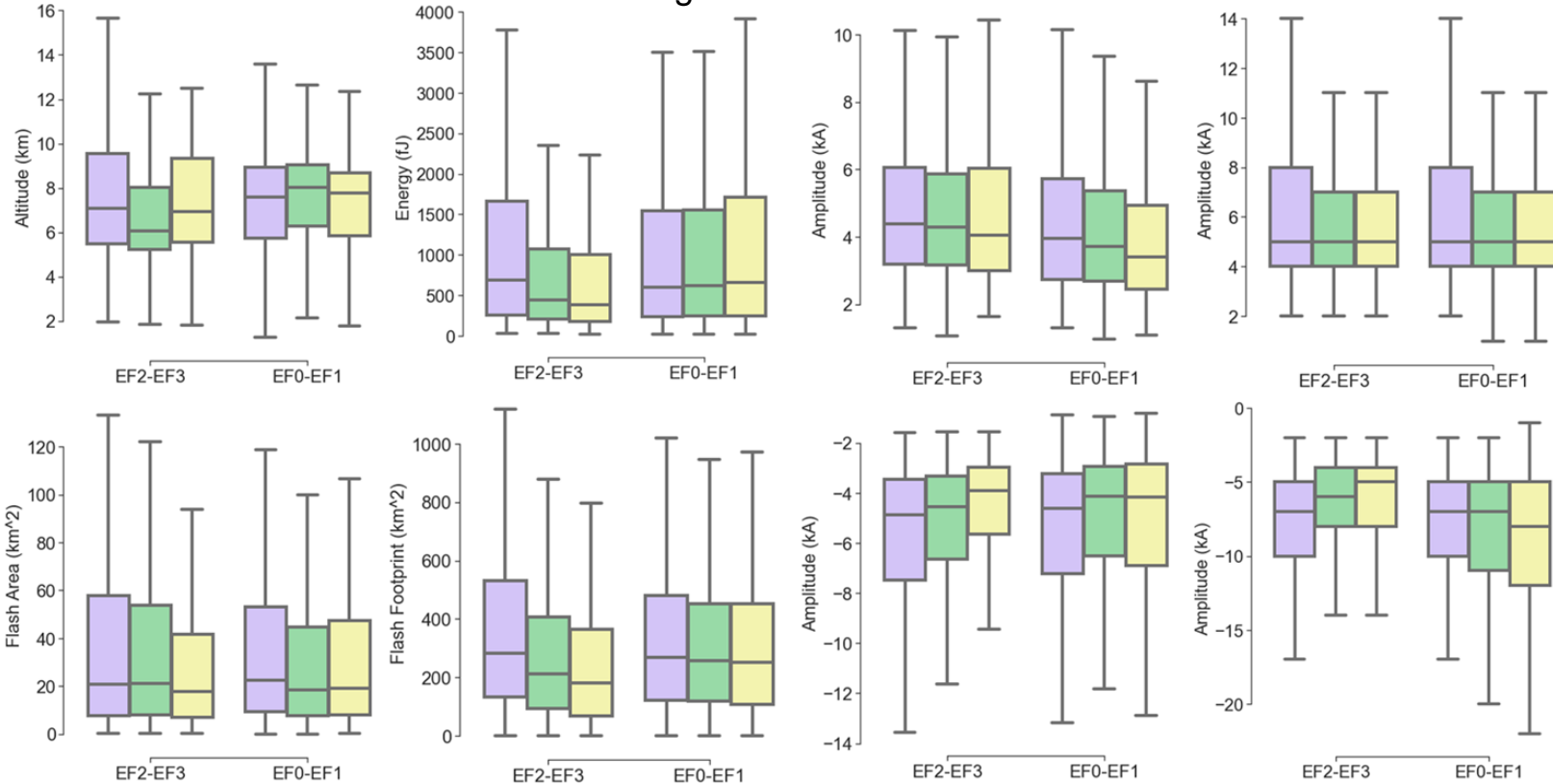
10 Minutes before Tornado



During Tornado



10 Minutes Following



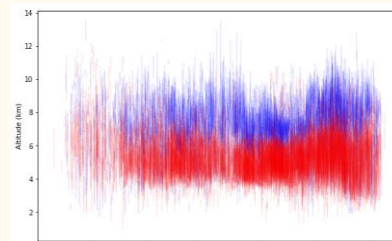
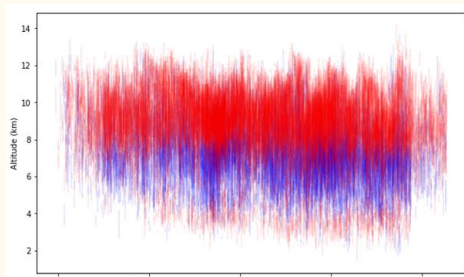
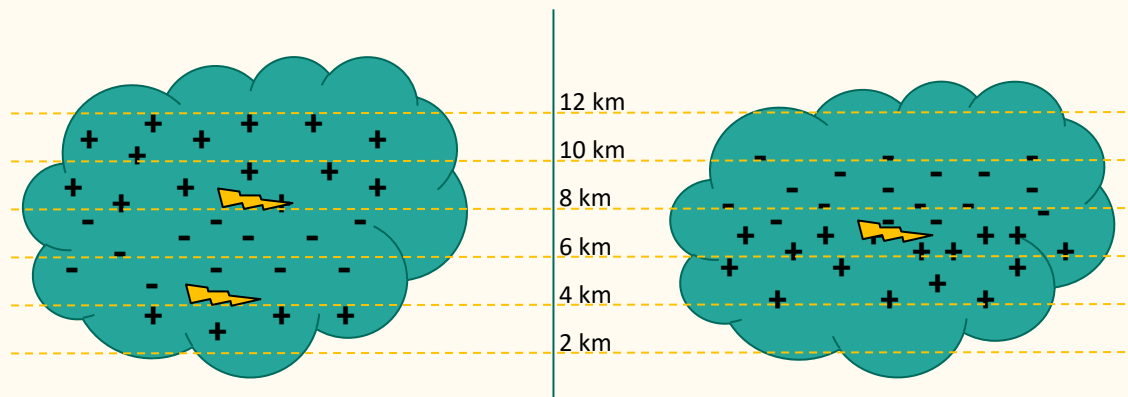
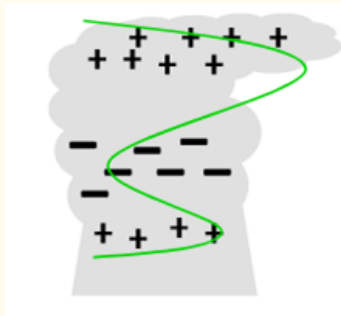
Flashes that are:

- higher altitude,
- larger area,
- higher energy

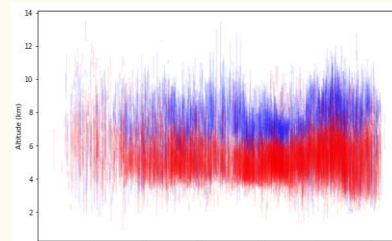
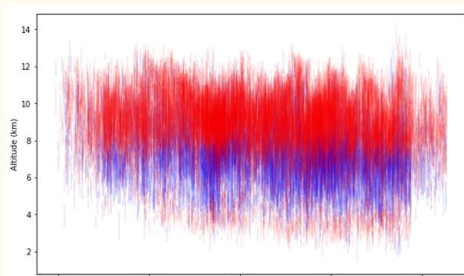
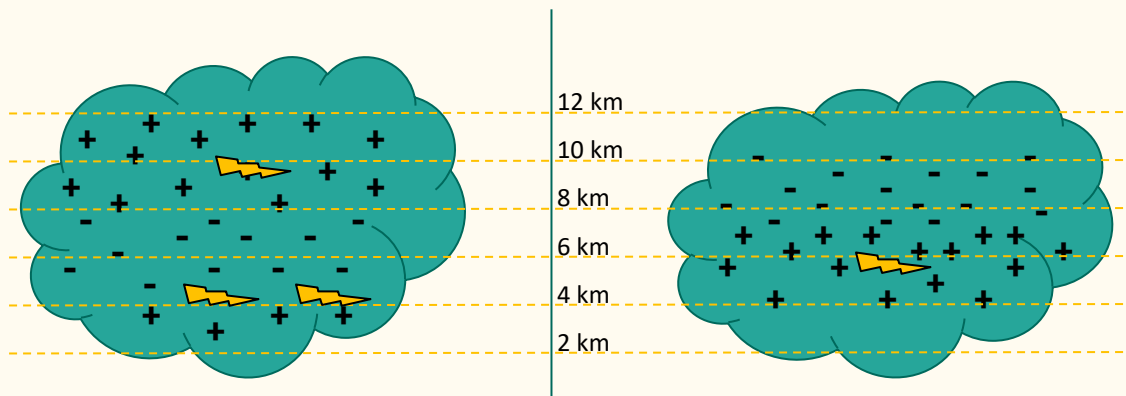
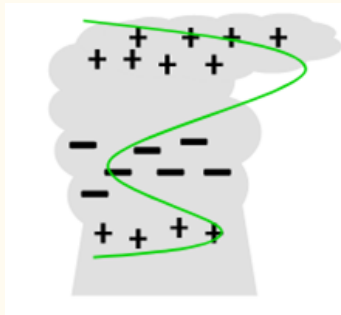
occur prior to tornado

On average, Flashes are higher, less energetic, and smaller surrounding tornado than entire QLCSs

Overall

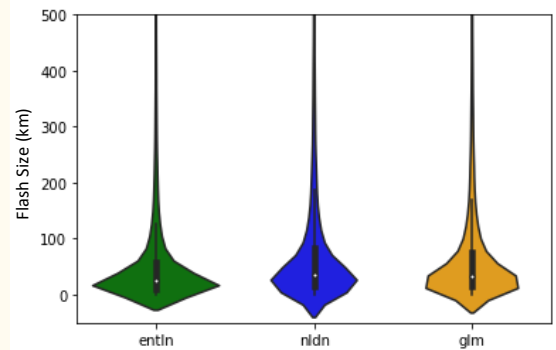
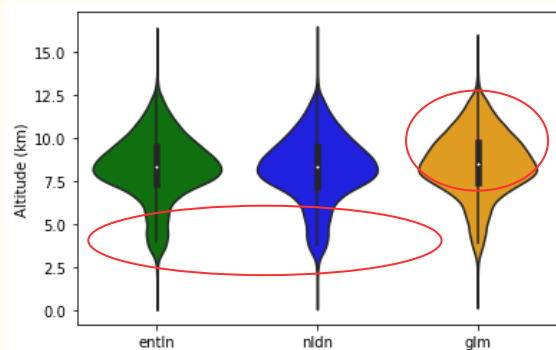


Tornadoes

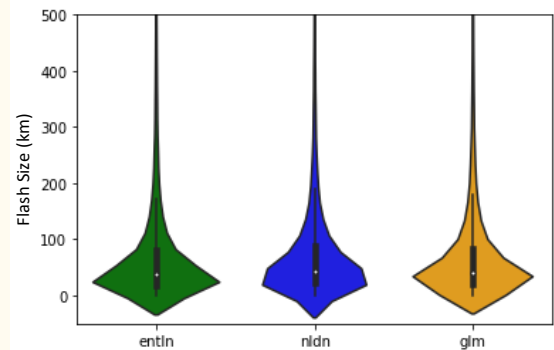
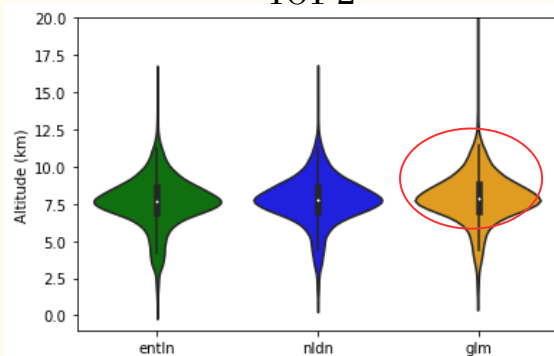


Characteristics of LMA flashes that Each Network Matched to

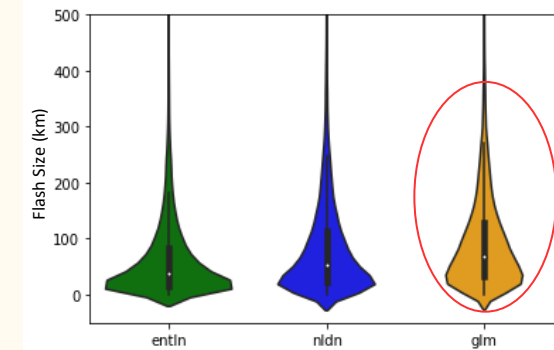
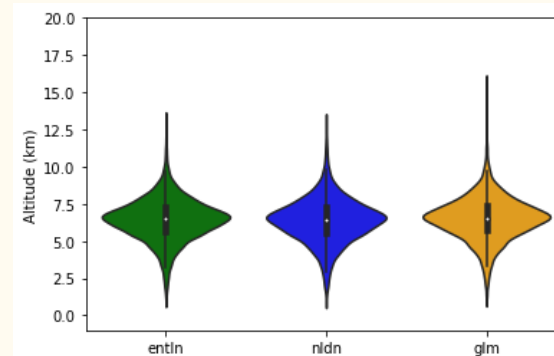
IOP1



IOP2



OK Case

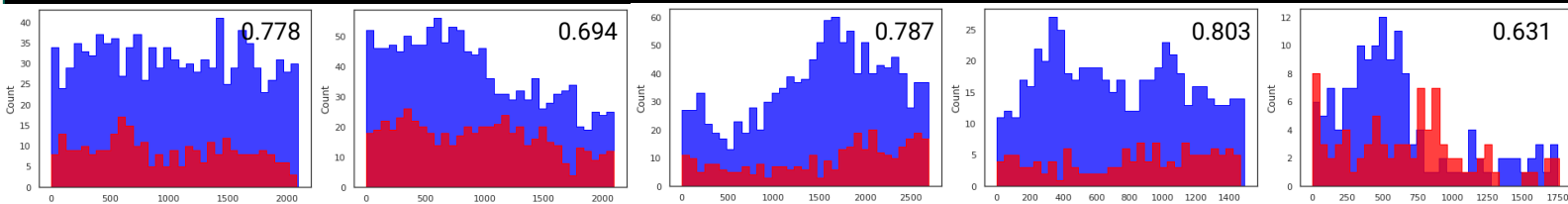


Altitude: Secondary peak in matched flashes

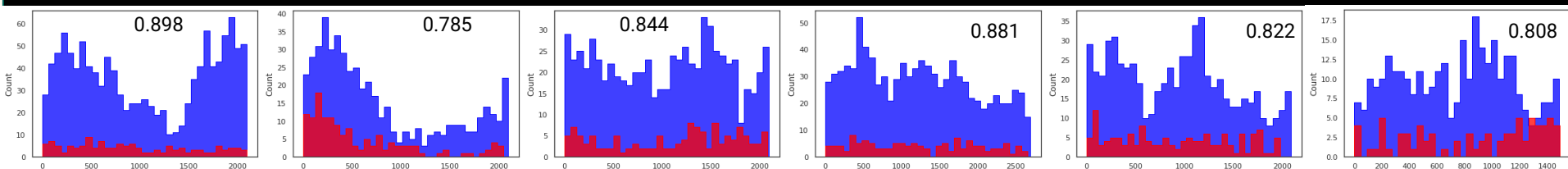
ENTLN Flash Type

red=CG, blue=IC

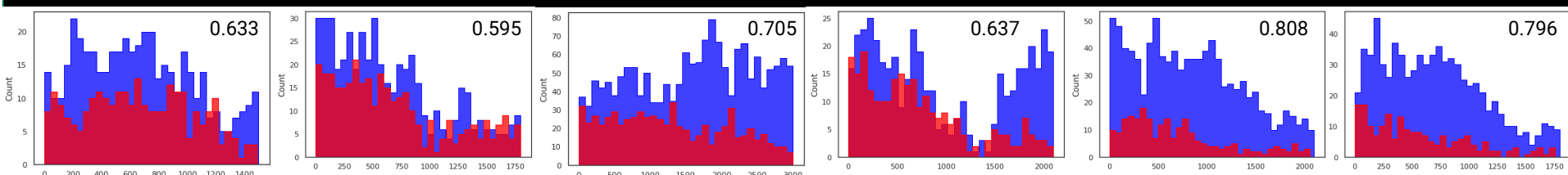
IOP1



IOP2



OK Case



Data

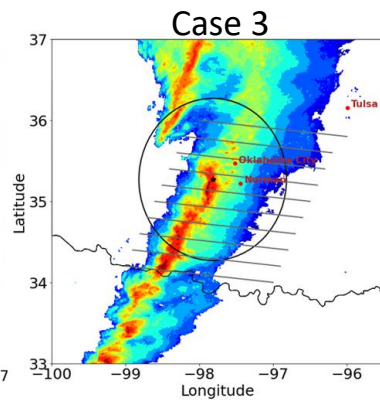
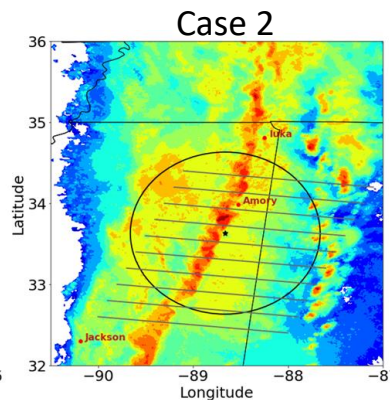
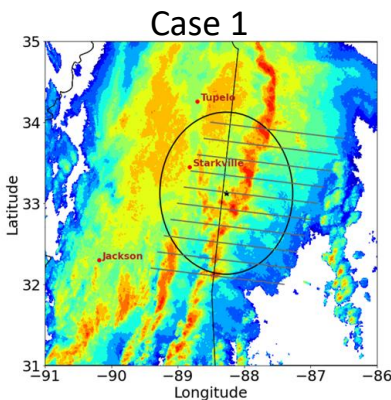
Want to compare how lightning networks behave during tornadoes

4 Lightning Networks:

- Lightning Mapping Array (LMA)
- Earth Networks Total Lightning Network (ENTLN)
- National Lightning Detection Network (NLDN)
- Geostationary Lightning Mapper (GLM)

3 QLCSs:

- Case 1: IOP1 March 22, 2022
- Case 2: IOP2 March 30, 2022
- Case 3: OK February 26, 2023



	Case 1	Case 2	Case 3
SBCAPE (J/kg)	500	700	250
0-3 km SRH (m^2/s^2)	380	400	600
0-6 km Bulk Shear (m/s)	18	15	20
EL (km)	12.5	11.6	11.1

