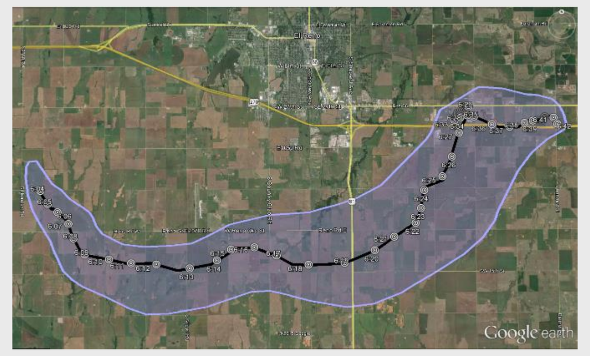
A Comparison of Lightning Flashes Observed by Ground-Based Detection Networks and Video

James Coy[1,2] and Kristin M. Calhoun[3,4]

[1]Research Experiences for Undergraduates, [2]Texas A&M University, [3]Cooperative Institute for Mesoscale Meteorological Studies, [4]NOAA/National Severe Storms Laboratory

Background

On 31 May 2013, a supercell rapidly developed west of El Reno, Oklahoma and produced a tornado that would become record-breaking. Many storm chasers were there to record the event while unintentionally capturing cloud-to-ground (CG) lightning flashes. A website, El-Reno-Survey.net, was created by multiple scientists to crowd-source the estimated more than 300 chaser videos to make the information available to the scientific community. In order to synchronize the chaser videos, the team initially used lightning flashes captured by the chasers combined with millisecond data from National Lightning Detection Network (NLDN). However, initial comparisons revealed some CG flashes in the videos that were not detected by NLDN as well as many NLDN recorded flashes that were not captured by a single chaser video. For this study, we compare the chaser videos of lightning activity with the NLDN and other ground-based detection networks, the Earth Networks Total Lightning Network (ENTLN) and the Oklahoma Lightning Mapping Array (OKLMA), to provide a more complete picture of the lightning activity of associated with this storm. Due to recent changes in the ENTLN algorithm, a pre- and post-statistical comparison of the video and instrumental data was also done.



Data Sources

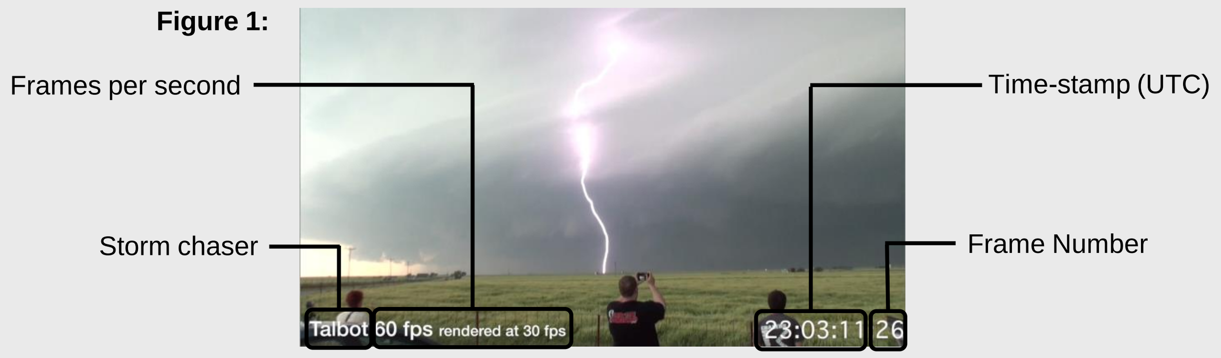
National Lightning Detection Network (NLDN): Consists of over 100 sensors roughly evenly distributed across the continental United States. Detects low frequency (30 kHz-300 kHz) or very low frequency (3 kHz-30 kHz) source of a lightning flash. Detections are limited to CG return stories and very energetic in-cloud (IC) processes (Cummins et al, 1998). Time (ms), latitude, and longitude as well as peak current are used from the NLDN. CG detection efficiency by the NLDN is estimated to be 95% with 40-50% for IC flashes.

Earth Networks Total Lightning Network: A networks currently consisting of over 800 sensors throughout 40 countries around the world. Like the NLDN, the sensors use waveforms to detect a lightning flash occurrence. The sensors use a wideband system (1 Hz-12 MHz) to detect weak IC flashes in addition to CG flashes. Though the sensors are not as evenly distributed across the United States, over central Oklahoma detection efficiency is around 90-95% for CG flashes and 70-80% for IC flashes.

Oklahoma Lightning Mapping Array (OKLMA): A cluster of 11 stations in central Oklahoma. Each station detects impulsive signals emitted by a developing lightning channel at very high frequency (VHF, Ch. 3, 60-66 MHz). Uses a time-of-arrival system to locate sources with location accuracy of 10-50 m in the center of the network. The OKLMA does not differentiate between IC and CG flashes, but has a detection efficiency around 95-99% over the center of the network for all lightning flashes..

El-Reno-Survey.net Videos: Each video consists of the chaser name, frames per second, and a time-stamp at the bottom right in UTC (Figure 1). In this study, lightning flashes were examined between *22:30:00 UTC (5:50 CST) and 23:30:00 UTC (6:30 CST)*. Used as "truth" for CG strike or flash confirmation.

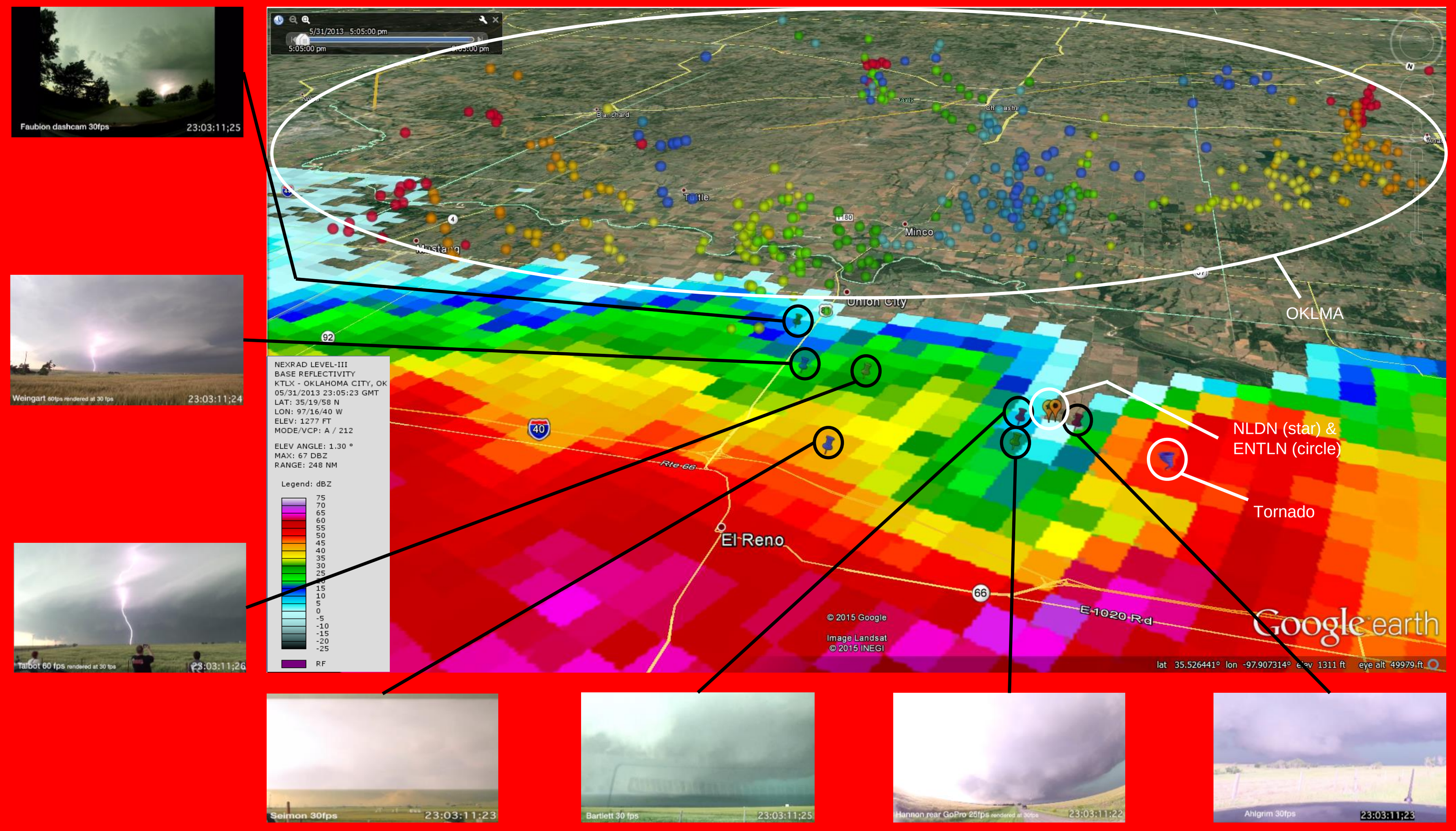
Figure 1:



Methods

1. The videos that were provided came with metadata created in Microsoft Excel that consists of all video recorded CG flashes matched with NLDN recorded flashes by the millisecond. This format was incorporated to include ENTLN and OKLMA data. Locations of each of the chasers were discovered through common roads and landmarks.
2. NLDN and ENTLN data include the time-stamp (UTC), latitude/longitude (degrees), and an estimated peak current (ampere, A) value of each flash. Negative/positive ampere values represent flashes of negative/positive polarity. Following our initial analysis, a 15 kA (15000 A) filter was used to isolate significant flashes and eliminate possible misclassified IC.
3. IDL software created by New Mexico Tech, X-LMA, was used to examine OKLMA data. Flashes that contain at least 10 or more VHF sources were examined and given a charge analysis to confirm the polarity of the CG flash.
4. Using a Python program, each CG flash recorded by the NLDN, ENTLN, and OK-LMA data along with the locations of the storm chaser and tornado were plotted on Google Earth for a 3-dimensional representation.
5. Comparisons between the two lightning networks (NLDN and ENTLN) and then video and LMA were done. Initial focus was on distance and polarity agreements.

Google Earth and Video Visual Comparison (23:03:11 +CG Strike)



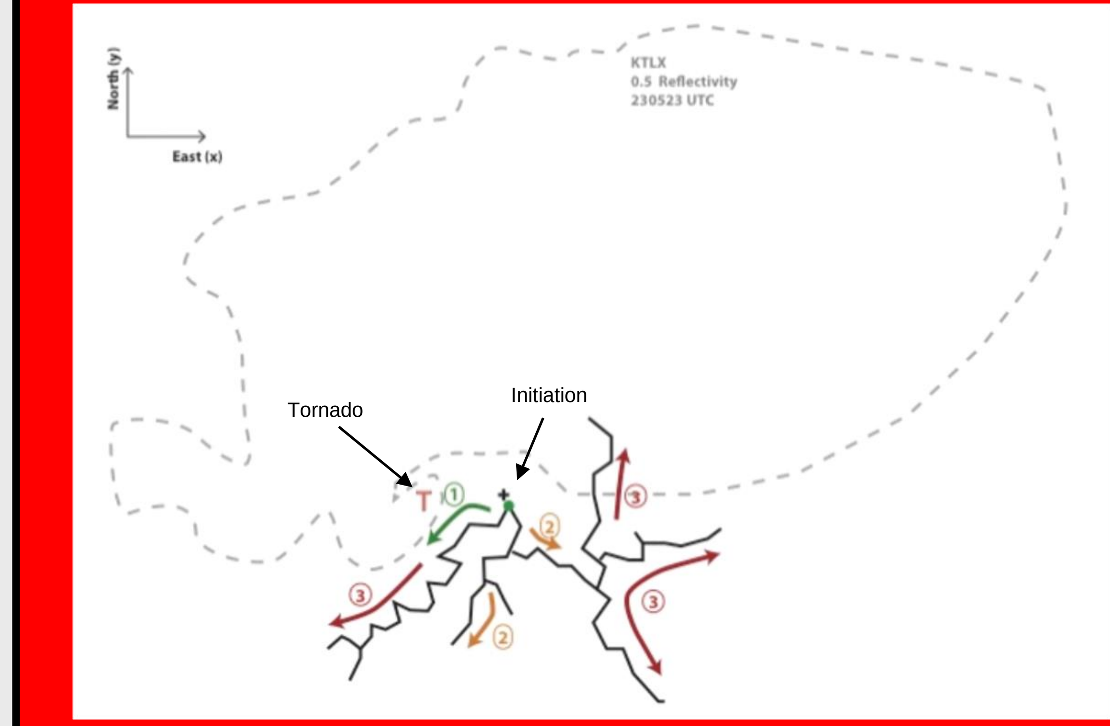
CG flash at 23:03:11 UTC as observed by the OKLMA, NLDN, ENTLN, and storm chaser footage with KTLX reflectivity overlay (moments before the tornadogenesis).

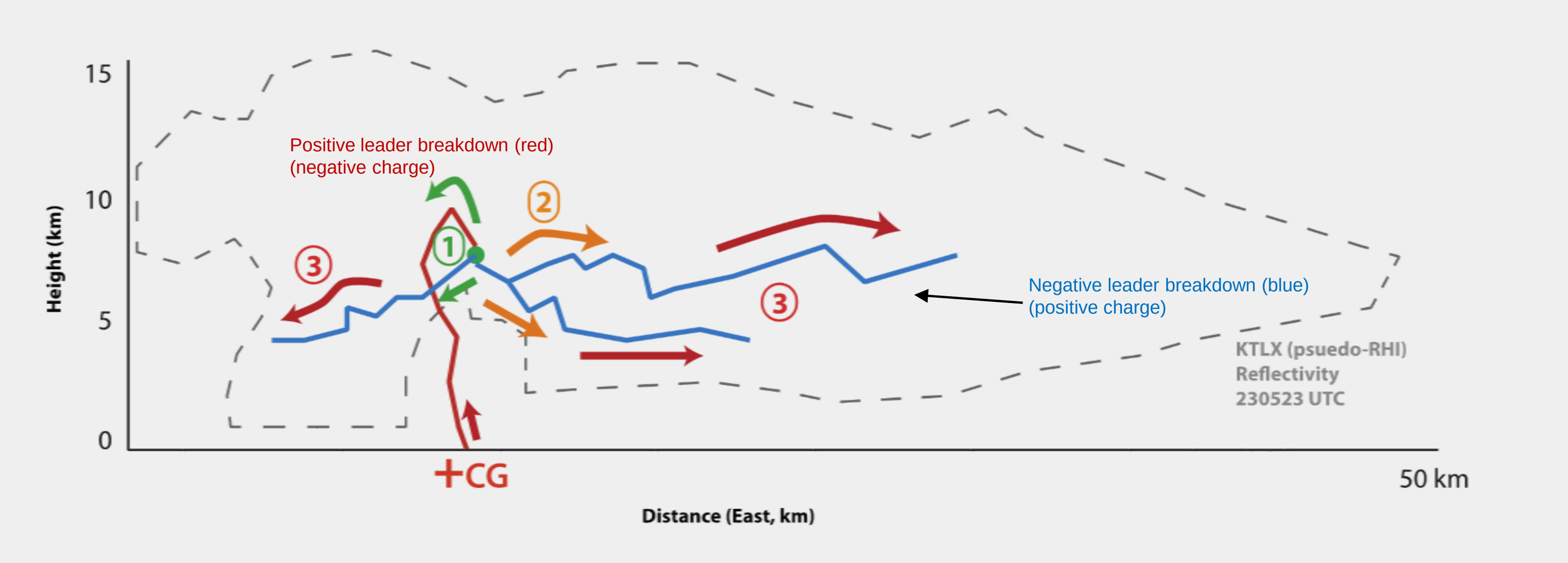
The NLDN and ENTLN both detected postive CG flashes with ground locations as shown in Google Earth (above) within 256 m of each other. However, NLDN peak current was 82 kA while ENTLN was only 40 kA.

Video stills from footage from Bartlett, Hannon, and Ahlgrim are from locations that were closest to the NLDN and ENTLN markers but instead of capturing a CG strike, they captured a blinding flash which was eventually followed by a thunderclap. The footage from Faubion, Weingart, and Talbot were furthest away from the strike and actually captured it.

(Left and Below) Full illustration of entire 23:03:11 UTC lightning flash as seen by the OKLMA. Lightning was initiated between upper negative and mid-level positive charge regions. The positive leader first progressed (green arrows) upward before progressing to ground outside of the cloud (as seen in the video). The negative leaders propagated multiple directions in-cloud (orange arrows), with the majority of breakdown (red arrows) occurring after the connection with ground was made producing continuing current.

Visual Comparison (OKLMA Illustration/Charge Analysis)





Statistical Comparisons (Pre-ENTLN Update)

NLDN and ENTLN

Table 2:

NLDN CG Flashes	ENTLN CG Flashes	Total CG Flashes	NLDN % -CG	NLDN % +CG	ENTLN % -CG	ENTLN % +CG	% Agreed Polarity	Avg. Distance Agreement (m)
2117	1672	3232	58%	42%	77%	23%	72%	2321
1682 (15 kA filter)	*1113 (15 kA filter)*	*557 (NLDN/ENTLN)*	*16% (15 kA filter)*	*84% (15 kA filter)*	*63% (15 kA filter)*	*37% (15 kA filter)*	*53% (15 kA filter)*	*1232 (15 kA filter)*

Figure 2

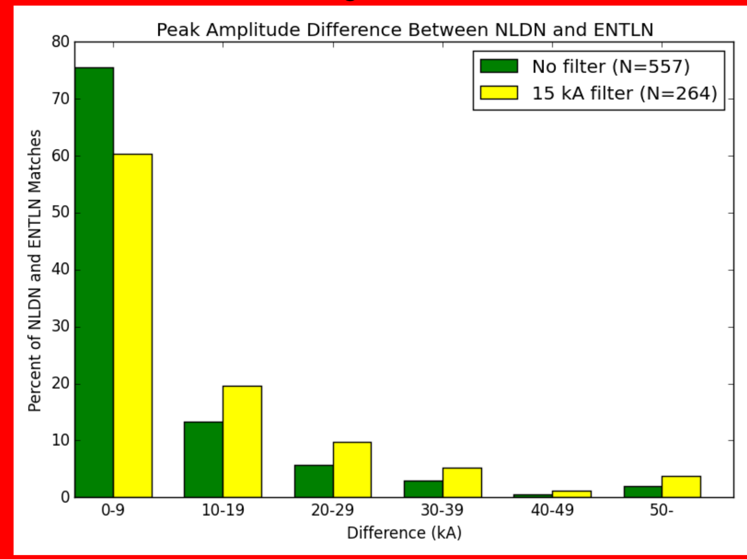
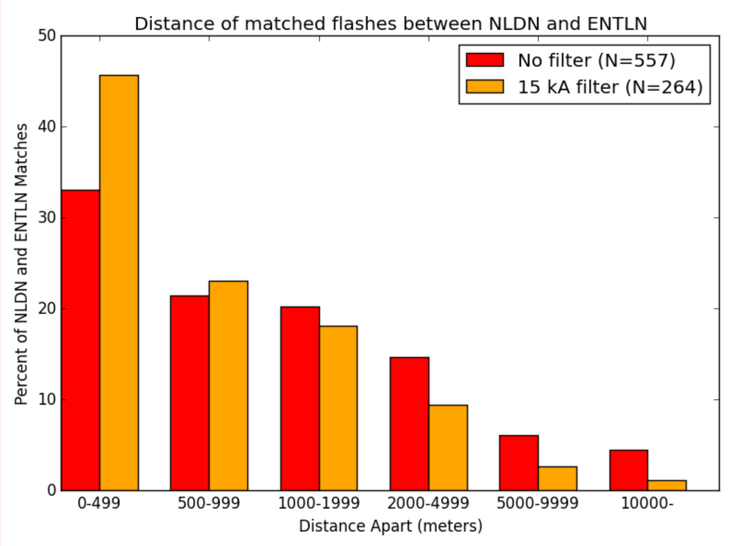


Figure 3



OKLMA and Video

Table 3:

Video Flashes	Other High Amplitude (kA) flashes	LMA Analyzed CG flashes	LMA Inferred +CG	# NLDN	NLDN % +CG	# ENTLN	ENTLN % +CG
170	29	199	100%	178	96%	175	48%

Statistical Comparisons (Post-ENTLN Update)

NLDN and ENTLN

Table 4:

NLDN CG Flashes	ENTLN CG Flashes	Total CG Flashes	NLDN % -CG	NLDN % +CG	ENTLN % -CG	ENTLN % +CG	% Agreed Polarity	Avg. Distance Agreement (m)
2117	1746 ↑	3199 ↓	58%	42%	77%	23%	97% ↑	1293 ↓
1682 (15 kA filter)	*578 (15 kA filter)* ↓	*664 (NLDN/ENTLN)* ↑	*16% (15 kA filter)*	*84% (15 kA filter)*	*31% (15 kA filter)* ↓	*69% (15 kA filter)* ↑	*97% (15 kA filter)* ↑	*803 (15 kA filter)* ↓

Figure 4

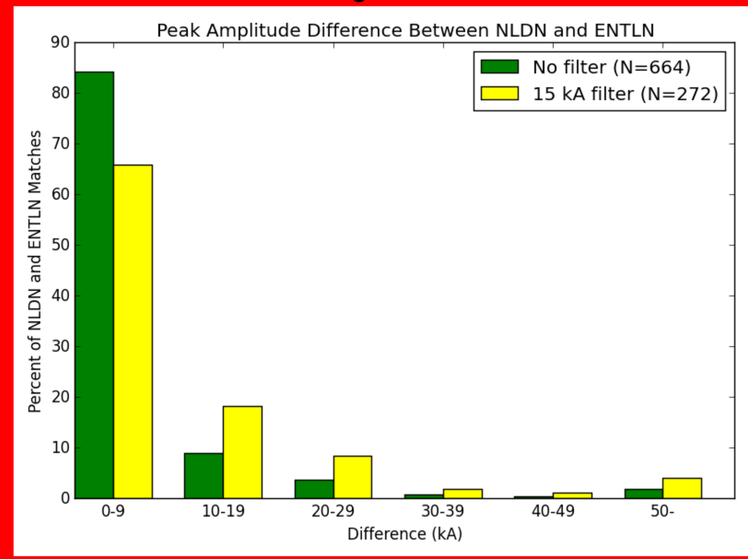
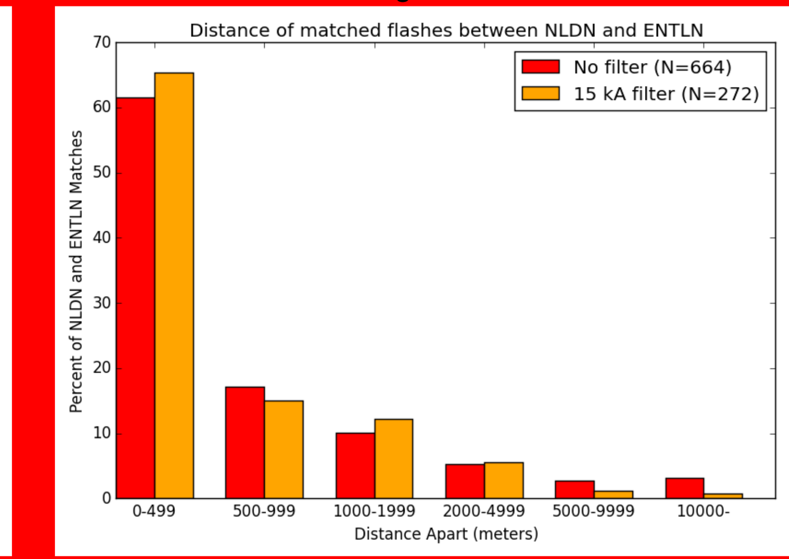


Figure 5



OKLMA and Video

Table 5:

Video Flashes	Other High Amplitude (kA) flashes	LMA Analyzed CG flashes	LMA Inferred +CG	# NLDN	NLDN % +CG	# ENTLN	ENTLN % +CG
170	29	199	100%	178	96%	182 ↑	97% ↑

Discussion (Pre-ENTLN Update)

Table 2: The CG polarity values enclosed in the black boxes highlight the conflicting polarity observations between the two networks. Without the 15 kA filter, 72% of the 557 NLDN and ENTLN matched CG flashes were of the same polarity, after the 15 kA filter application this is reduced to 53%. Table 6 (below), shows an example of the polarity disagreements. Despite NLDN classifying these as +CG and being the most intense in peak current, ENTLN classifies them as –CG yet still records the peak currents as very high in magnitude.

Table 6:

UTC time (HH:MM:SS)	miliseconds	NLDN PEAK CURRENT (kA)	EN PEAK CURRENT (kA)
23:13:30	0.5745	247	-224
22:54:21	0.9162	226	-226

Note: Deep contrast in polarity reports in NLDN and ENTLN data. –CGs rarely exceed 100 kA in peak current unlike +CGs.

Figure 2: The peak current comparison chart ignores the signs of the values and deals with only the magnitude as a good amount of matched CG flashes would have 50+ kA peak current differences (Table 6). The 0-9 kA difference interval decreases in percentage after the application of 15 kA filter while all other difference intervals have a slight increase.

Figure 3: The location matching between the two networks increased after the application of the 15 kA filter with the most percentage increase in the 0-499 meters distance interval. Likely due to misclassified IC flashes with lower peak currents generally more unknown.

Table 3: Out of the 25 storm chaser videos that were provided, 6 were completely analyzed. 170 video confirmed CG flashes along with 29 other high peak amplitude CG flashes were analyzed by the OKLMA. All 199 flashes were inferred to be +CG through the charge analysis though 4% of them were –CG by NLDN similar to the results listed in Table 2, ENTLN reported only 48% of them to be +CG.

Discussion (Post-ENTLN Update)

Table 5: Despite the increase in ENTLN confirmed CG flashes compared to Table 2, there is a decrease in total CG flashes, however, there is an increase in the amount of NLDN and ENTLN matches. There is a significant increase in agreed polarity with and without the filter which resulted in the ENTLN observing more +CG flashes than -CG like the NLDN. Table 7 (below), shows examples of what contributed to the increase after the update. There are decreases in average distance agreements with and without the filter.

Table 7:

UTC time (HH:MM:SS)	miliseconds	NLDN PEAK CURRENT (kA)	EN PEAK CURRENT (kA)	EN PEAK CURRENT II (kA)
22:38:55	0.6447	39	-44	42
22:42:33	0.7827	40	-35	35

Note: ENTLN's conversion from –CG (before update) to +CG (after update).

Figure 4: As done on Figure 2, the peak current comparison chart ignores the signs of the values and deals with only the magnitude. There is an increase in the percentage of the 0-9 kA differences with and without the filter compared to Figure 2. The chart follows a similar trend for the higher difference intervals.

Figure 5: Compared to Figure 3, there is a significant increase in the percentage of 0-499 meter distances between NLDN and ENTLN. As a result, the greater distance intervals have a notable decrease.

Table 6: The CG flashes analyzed by video and OKLMA are the same as the ones analyzed in Table 3. Compared to Table 3, the percentage of ENTLN recorded and OKLMA analyzed CG flashes that were positive increased from 48% to 97%, matching NLDN's +CG percentage.

Conclusions

- Before the ENTLN received the update in its flash algorithm, the CG flashes that were recorded by the network had a stark polarity contrast in over half of them with and without the 15 kA filter. Even the NLDN and ENTLN matched CG flashes had a great polarity disagreement.
  - The statistical comparisons done on the NLDN and OKLMA both infer that the storm was +CG dominant between 22:30:00 UTC and 23:30:00 UTC but ENTLN infers a mix of the two polarities.
  - This conflict could cause researchers who rely on NLDN and ENTLN data to be confused in trying to determine the storm's charge structure though CGs only make up a portion of the decision.
- After the ENTLN update, there were near 100% polarity agreements for NLDN and ENTLN matched CG flashes with or without the 15 kA filter. This increase in polarity agreement carries over when compared to the OKLMA charge analysis. The average distance between the recorded locations of the matched CG flashes also decreased with or without the 15 kA filter.
  - Given the consistency in the percentage of +CG reports by the NLDN and OKLMA, the update to the ENTLN seems to be an improvement as all the ground-based networks as now all ground-based networks indicate that the storm was +CG dominant at the time
- A more extensive study involving the entire supercell and a timeframe allowing to observe the storm's evolution would make it possible to study the ground-based networks' performances in detecting –CG lightning while also being cautious of low peak current flashes that are in fact IC flashes.

Acknowledgements

- Dr. Anton Seimon for providing the storm chaser video footage and initial NLDN and video findings.
- The corresponding author would like to thank his mentor Dr. Kristin Calhoun for her assistance throughout the term of the project and internship.
- The corresponding author would also like to thank Dr. Daphne LaDue for selecting him to participate in the Research Experience for Undergraduates at the National Weather Center in Norman, Oklahoma.
- This research was supported by the National Science Foundation Grant (NSF) AGS-1062932.
- Funding was also provided by NOAA/Office of Oceanic and Atmospheric Research under NOAA-University of Oklahoma Cooperative Agreement NA11OAR4320072, U.S. Department of Commerce.