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Locations of Cloud-to-Ground Lightning in a Convective Storm

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Abstract

Cloud-to-Ground (CG) lightning examined using data from the National Lightning Detection Network (NLDN) over a six-hour span of a supercell thunderstorm that formed in Texas on 20 May 2019. The first echoes occurred at 0550 UTC on the border of Lynn and Garza counties in Texas. The storm moved off to the northeast and strengthened into a tornadic supercell. CG lightning is analyzed during the formation stage, mature stage, and dying stage of this convective storm. Latitude and longitude coordinates are provided from the NLDN every time a CG strike occurs during this supercell thunderstorm along with the strength of each strike and the type of charge (positive or negative). Findings using the NLDN data set are compared with the findings analyzed by Keighton et al (1991) of CG lightning in Mesoscale Convective Complexes (MCS). Cloud-to-Ground (CG) lightning location is The behavior of the location of CG strikes during the three previously mentioned stages of convective storms will be analyzed and compared with previous work.

1. Introduction

The locations of Cloud-to-Ground lightning in a supercell thunderstorm that formed on 20 May 2019 in Garza county Texas will be analyzed using data from the National Lightning Detection Network (NLDN). Geographical Information Systems (GIS) were also used to display radar data overlaid with latitude and longitude coordinates of each lightning strike during the life cycle of the supercell. Analyzing the behavior of CG lightning during the life cycle of supercell thunderstorms could unveil the complexities of the processes that spawn this dangerous phenomenon.

Lightning within a convective storm has been an area of interest for atmospheric scientists since the 1980's. Goodman and MacGorman (1986) used the National Severe Storms Laboratory's (NSSL) lightning detection and location network to investigate CG lightning within a Mesoscale Convective System (MCS). This technology introduced in the 1980's allowed for detailed studies of CG lightning. The authors found that an MCS can contain 1000 CG lightning strikes per hour for a duration of nine hours on average with peak rates of 2700 CG strikes per hour.

The study of CG lightning in MCS's was expanded in a case study of a MCS that formed in Oklahoma on 23 May 1981. Keighton et al (1991) focused their efforts on CG lightning and storm structure in the formation stage, supercell stage, and squall-line stage of this MCS. They found that CG lightning was scarce during the formation stage and occurred well outside of the highest reflectivity region of 10 dBZ. Instead, CG lightning occurred on the edge of the 5 dBZ region where the authors speculated that the lightning must have originated in the anvil of the storm. The updraft proved to be an important talking point for its effect on the location of CG lightning in an MCS.

During the beginning of the supercell stage, the authors found that CG lightning frequency increased substantially with clusters of CG strikes near the locations of updrafts and mesocyclones. Keighton et al (1991) emphasizes the correlation of CG lightning frequency with convective growth above eight kilometers where particle interaction in temperatures ranging from 0°C to -25°C carry more charge in a colder environment. Most of the CG lightning was located near the reflectivity core of 40 dBZ to 50 dBZ and just outside the highest reflectivities of 55 dBZ and 60 dBZ during the supercell stage.

Shortly after the supercell produced multiple tornadoes, other convective storms began to form to the west and southwest of the original cell and merged into a squall-line. The squall-line stage is where Keighton et al. (1991) observed the peak of CG lightning flash rates in and around the 55 dBZ region. They observed that as the updraft weakened during this stage, the area of stratiform precipitation grew behind the original convection, which is typical of squall-lines. In this stratiform region, a relative maximum in CG strikes occurred behind the highest reflectivity as the MCS began to wind down. They speculated that an excess of cloud particle debris and precipitation caught up in the updraft of the storm began to filter out towards the rear of the highest reflectivity advecting charge with it, thus leading to an increase in CG lightning in the stratiform region.

The stratiform region's correlation with CG lightning was also examined by Peterson and Rutledge (1998) where their specific study focused on the "rain yield". The rain yield is simply the ratio of rain mass to CG lightning flash count over a common area and is affected by the stratiform precipitation that falls in an MCS. The authors found that tropical rain yields are less than mid-latitude rain yields because of the lack of ice particles in tropical convection in which charge separation is harder to achieve and particle collisions are less charged.

Reap and MacGorman (1989) similarly examined CG lightning and its correlation with moisture flux, time of day, and positive and negative CG flashes over a long period of time. The authors used the WSR–57 radar to correlate low-level moisture flux with both positive and negative lightning strikes. They found a positive correlation between CG lightning and low-level moisture as stated in past studies. The authors also noticed a trend in the less common positive lightning strike to be occurring in the late afternoon and during the night while both kinds of CG strikes occurred most often between 4 pm and 10 pm.

The main goal of this research is to dissect the 20 May 2019 case study and analyze the timing and locations of CG strikes throughout the life of the storm. Data from the National Lightning Detection Network (NLDN) will be analyzed during the formation stage, mature stage, and dying stage in the convective storm. This will give insight to how lightning will behave during these stages and can be compared with studies completed in the past.

The next section will describe how the data was collected and the methodology behind using and analyzing the data set. Section 3 will present the results of this case study and section 4 will discuss these results. Lastly, section 5 will conclude the study and discuss potential future work.

2. Description of Texas Supercell

The supercell thunderstorm analyzed in this study formed in Garza county Texas on 20 May 2019 at approximately 1 pm CST and lasted until 7 pm CST. This supercell produced multiple tornadoes as it propagated toward the northeast, moving through north east Texas, and eventually crossing the Texas-Oklahoma border. The environment that day was conducive for supercell formation as evident by how long this supercell was able to sustain itself. Low-level moisture, wind shear, and instability created an environment for long track supercells and made the analysis for CG lightning throughout its different stages sufficient. The analysis period for the formation stage begins shortly after the first echoes at 1:23 pm CST and ends at 1:51 pm CST. The analysis period for the mature stage begins at 4:45 pm CST and ends at 5:15 pm CST. Finally, for the dissipation stage, the analysis period is from 6:15 pm CST to 6:45 pm CST.

3. Data and Methodology

The lightning data used in this study were collected from the Vaisala National Lightning Detection Network (NLDN). The NLDN detects real time lightning strikes with impressive accuracy and delineates between Cloud-to-Ground lightning strikes and Cloud-to-Cloud lightning strikes. The data source gives latitude and longitude coordinates for every strike location across the United States. Other parameters given are the time of the strike in UTC, signal strength, and charge (positive or negative) in kiloamps.

The data were imported and accessed using a metpy script that utilized Albany's Local Data Manager (LDM) to access the NLDN data. The script transformed the binary files into an output file that could then be put into an excel spreadsheet. Organizing the data into a neatly row and columned space format allowed for the data to be imported into another type of software to display the lightning strike locations overlayed with radar data.

Geographical Information System (GIS) was able to achieve this method of displaying the data properly. Once the data were imported into GIS, CG strikes were displayed at the exact location of every strike within the chosen time frame and box number. Using specific commands in the metpy script, the lightning strike coordinates were trimmed down into three box number locations. Box number one was the region the supercell was in during the formation stage. Box number two was the region covered in the mature stage of the supercell. And box number 3 was the region the supercell was in during the dying stage.

4. Results

In box number one during the formation stage of this supercell thunderstorm, most of the CG lightning occurred outside of the highest reflectivity region of 60 dBZ and even outside the 50 dBZ region. Most of the lightning activity was confined to the 40 dBZ region and displaced from the core of the supercell towards the north and east. One of the strikes is outside reflectivity of 5 dBZ or less during this stage as well.

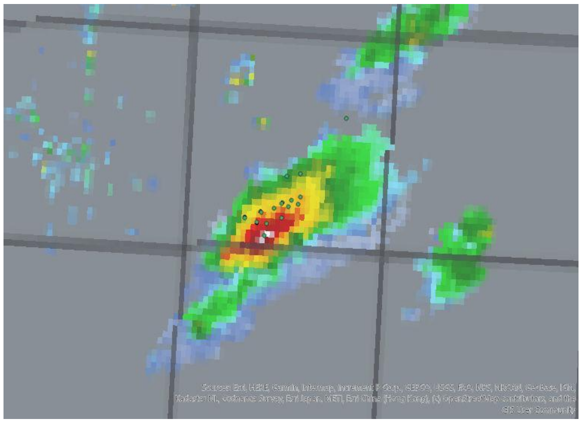

Figure 1. Cloud-to-Ground lightning strikes represented by the green shaded dots overlayed with this radar image during the formation stage.

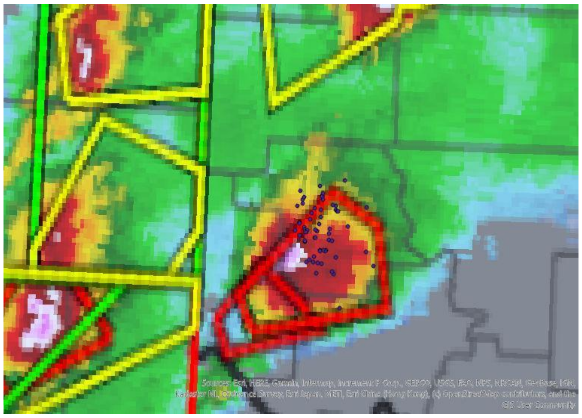

Figure 2. Cloud-to-Ground lightning strikes represented by the blue shaded dots during the mature stage.

In box number two during the mature stage of the supercell, more of the CG lightning occurred within the 50 dBZ region but still just outside the area of highest reflectivity of around 65 dBZ and displaced off to the north and east. The 40 dBZ region was still active with CG lightning during this stage of the thunderstorm. In box number three, during the dying stage of this storm, CG lightning was closer to the core of the supercell than in the other two stages. The region of highest reflectivity during the dying stage was around 55 dBZ or less as the storm began to wind down and become absorbed by other cells around it. Throughout the dying stage, CG lightning continued to cluster around the highest reflectivity.

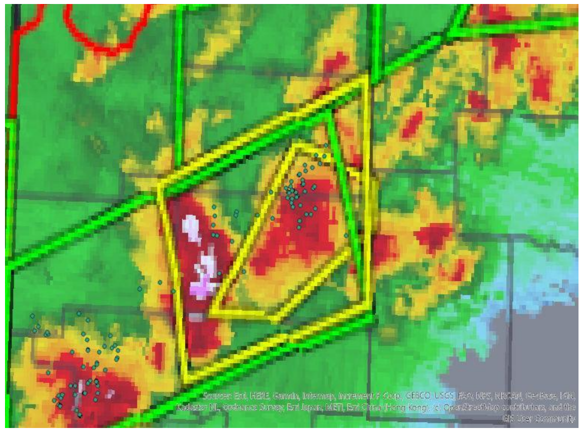

Figure 3. Cloud-to-Ground lightning represented by the cyan colored dots during the dying stage.

5. Discussion

The location of CG lightning occurring well outside the area of highest reflectivity during the formation stage is consistent with the study done by Keighton et al (1991). It is suggested that this occurs in part due to vertical wind shear and the tilting of the updraft as it advects charged particles near the anvil of the storm. The Storm Prediction Center's (SPC) forecast for 20 May 2019 suggested significant vertical shear of up to 60 knots within the low-level jet. This is especially evident with one of the strikes occurring outside of the 5 dBZ region of reflectivity. It is assumed this strike may have occurred in the anvil of the supercell as charged particles were carried toward that region and the connection between a negative and positive charge was made.

With the updraft still being strong in the mature stage of the supercell, CG lightning continued to occur outside the area of highest reflectivity of 65 dBZ. Charged particles are being displaced off to the northeast of the highest reflectivity region in the direction of the low-level jet coming out of the south and winds higher up coming out of the southwest. It is assumed that this is one of the reasons behind CG lightning location being outside the highest reflectivity until the updraft collapses.

In the dying stage of this supercell, it is assumed the updraft collapses and CG lightning therefore clusters near the highest region of reflectivity of 55 dBZ. Unfortunately, the stratiform region of this supercell as it collapses is not easily identifiable due to the formation of a new supercell to the west. However, the clustering of CG lightning around the highest reflectivity region is evident of a dissipating updraft and charged particles no longer being carried outside the core of the storm towards the north and east.

The location of CG lightning throughout all stages of this convective storm behaved as expected. Reap and MacGorman (1989) hypothesized that CG lightning location within the upper echelon of reflectivity has a lot to do with the horizontal and vertical wind structure in the storm which carry charged particles and concentrate them in certain locations within the convection. Locations of updrafts and mesocyclones are especially an area of interest when analyzing lightning location. The hypotheses in the previous studies were confirmed in this study as the CG lightning locations were concentrated within the highest reflectivity when the storm was no longer tornadic and the mesocyclone and updraft weakened. Alternatively, when the storm was tornadic and had strong updraft velocities and a formidable mesocyclone, the CG location was spread out within the higher reflectivity but located in the proximity of the mesocyclone and updraft.

6. Conclusion

The locations of CG lightning in convective storms proves to be challenging to diagnose. There are multiple processes that are involved when lightning strikes. The evidence presented in this study is consistent with past studies done on CG lightning in convective storms. In the future, the objective is to continue this study in more depth. As opposed to using only three still images of the radar loop during this supercell thunderstorm, the goal in the future is to overlay the whole loop to increase the understanding of the behavior of CG lightning throughout the storm's life cycle.

Nevertheless, the figures created using GIS pro yielded results that were able to be analyzed and compared to Keighton et al (1991).

7. Acknowledgements.

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8. References

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