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Examining the Lightning Characteristics of Several Types of Storms Using the Georgia Tech DBSCAN Based SCIT Algorithm

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Abstract

A storm cell identification and tracking (SCIT) algorithm which uses density based special clustering with applications in noise (DBSCAN) and joint probabilistic data association (JPDA) has been used to explore the relationship between severe storm evolution, particularly tornado touchdown, and lightning flash characteristics for two separate severe weather events which occurred in north Georgia. It has been found that the DBSCAN based SCIT algorithm was effective in tracking storm cell core reflectivity areas in both isolated supercell cases and for cores embedded in a quasilinear convective system (QLCS).

The DBSCAN based SCIT algorithm is briefly introduced at the start of the paper. A lightning dataset provided by Earth Networks was used for both cases. Several adjustable parameters used to tune the association of these lightning data with the reflectivity cores are discussed. The evolution of the lightning flash rates is examined for both types of events. This examination has shown that the DBSCAN based SCIT algorithm developed by GTRI is robust in its tracking abilities and useful in associating various storm parameters to individual cells. The association between the evolution of storm severity and flash rate change appears to be somewhat inconsistent in such a small subset of storms, leading to the conclusion that both more storms characteristics and more cases need to be examined to produce robust results.

Introduction

The SSRC was established to investigate severe local storms in the state of Georgia and to investigate methods of better detecting and predicting those storms. One of the efforts conducted under this mandate is an examination of the lightning characteristics of severe storms and the relationship between these characteristics and the evolution and severity of the parent storm. Toward this end, the SSRC has developed an advanced SCIT algorithm which is capable of tracking three dimensional radar reflectivity features in storm cells and then associating these features with any collocated variables (Matthews and Trostel, 2010) (Reed and Trostel, 2011).

In this example, radar reflectivity cell cores from both a QLCS and a supercell outbreak are used as input for the tracking algorithm and the total lightning product available from Earth Networks is used as a secondary, associated data set. Trends in total lightning have been shown to be related to the onset of tornadic episodes using lightning data from the North Alabama Lightning Mapping Array (NALMA). (Schultz, et al.. 2008) (Schultz, et al.. 2009) (Shultz, et al.. 2011).

Tracking these trends for storms with the different morphologies seen in the QLCS and the supercell outbreak is shown to be effective for both cases, although different tuning parameters are found for each case. Tracking has been found to be quite robust, in several cases tracking cells for over hundreds of kilometers.

The relationships seen between the trends in total lightning trends and tornadic touchdown seen in this limited examination both strengthen the case that a relationship seems to exist and point to the need the use of additional parameters to strengthen the ability to warning based on these storm features.

The GTRI SCIT Algorithm Usage

The GTRI SCIT algorithm application consists of three distinct steps. First, the radar reflectivity, usually obtained from a WSR-88D NEXRAD radar site, is used to define cell cores using the DBSCAN algorithm. These defined cells are then uniquely identified and tracked over the time period of interest using a JPDA tracking method. Finally, the total lightning data, obtained from an outside source such as the Vaisala National Lightning Detection Network (NLDN) or Earth Networks ENTLN datasets, is associated with each tracked cell and characteristic for that cell.

2.1 Cell Definition using DBSCAN

The GTRI DBSCAN cell definition algorithm is a multi-threshold, three dimensional clustering method. It uses a “density-based, special clustering algorithm with noise”, DBSCAN, which allows for the creation of irregular, concave and convex three dimensional objects, as shown in Figure 1.

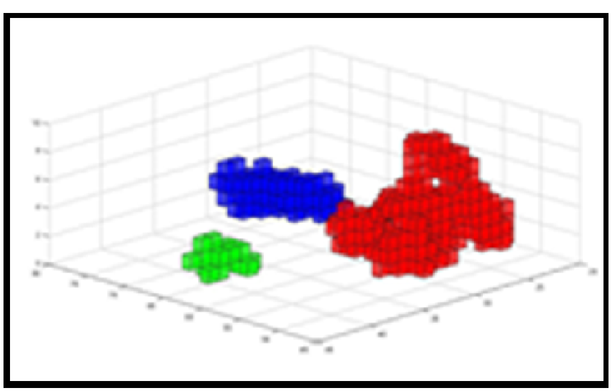
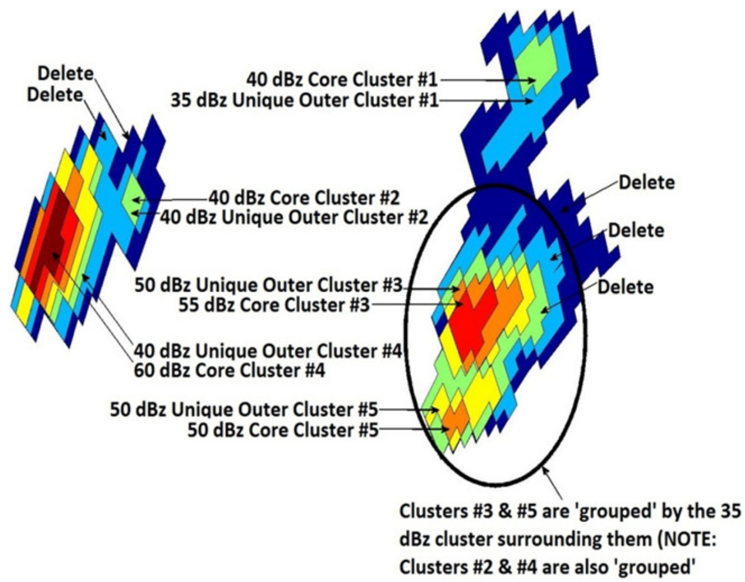


Figure 1. Three Dimensional Objects created using the DBSCAN algorithm

Several levels of objects are created at varying reflectivity levels. This allows for higher level reflectivity, inner “core clusters” to be associated with lower reflectivity “unique outer clusters”. A unique outer cluster is that group of reflectivity cells that uniquely surrounds a higher reflectivity inner cluster. In Figure 2, Cluster #1, with a maximum core reflectivity of 40 dBZ, is contained within a “unique outer core” of 35 dBZ. Cluster #4 in this figure has a higher, 60 dBZ core cluster, surrounded by a unique outer cluster at 40 dBZ.



2.2 Cell Tracking using JPDA

Once sets of objects have been defined for each radar scan using the DBSCAN cell definition algorithm, these cells are tracked using a complex Joint Probabilistic Data Association (JPDA) tracking algorithm. The details of this complex tracking algorithm are described in detail in earlier papers (Matthews and Trostel 2010).

The tracking can be applied to either core cell clusters or the larger, unique outer clusters surrounding these inner convective cores. The larger unique outer clusters seem to better characterize the larger parent storm cell in which convective core may reside.

The JPDA tracking algorithm allows both track splits and mergers, although in this study, only cell splits were allowed.

In one event studied here, comparisons were made of the cell tracking provided by the JPDA method with hand tracked cells for greater confidence in the operation of the algorithm.

2.3 Earth Networks Total Lightning Network

The Earth Networks Total Lightning Network (ENTLN) was used to provide total lightning information for the storm events studied. Earth Networks (formerly WeatherBug) launched the ENTLN in 2009. The network now consists of about 500 sensors globally. The wide band sensors detect lightning signals from 1 Hz to 12 MHz and can detect cloud to ground (CG), cloud to cloud (CC) and intra-cloud (IC) flashes. (It should be noted that CC/IC data was not available in 2009 data set.)

The ENTLN uses time of arrival (TOA) methods, utilizing multiple sensors to establish a common solution to determine the location of each detected lightning flash. By recording the waveform of each flash, the ENTLN is also able to determine flash characteristics such as type (CG, CC, IC), polarity (positive or negative), and charge transferred in the flash.

2.4 Method of Association

Records of flash type, location and time were used to associate the ENTLN data to individual tracked cell cores. As the inner cell core areas are often quite small, a buffer area was associated with each core. In this study, buffer areas of 5, 10 and 15 km around the cells were used. In order to temporally associate flash data with NEXRAD radar sweeps, a sliding time window was used to combine flash data to be associated with each NEXRAD radar scan.

NEXRAD radar scans, over all azimuth and all elevation angles, typically take about 5 minutes. The temporal association windows chosen to be used for the lightning data for this study ranged from 1 to 5 minutes.

For each radar scan, all flashes within the buffer area surrounding each tracked cell and within the temporal window about the nominal radar scan time were counted. This allowed a comparison of nine different choices of spacial and temporal association to be examined for the two storm events used in this study.

Case 1: QLCS

The first case studied was a QLCS which swept across the southeast US region on October 25th, 2010. This represents a difficult case for the cell tracking and identification as the cells were embedded within the linear structure and not always easy to separate in time or space.

3.1 Synoptics and Overview

On October 25th, a short wave tracked across the southern United States (US). This resulted in severe thunderstorms and several tornadoes from east Texas eastward into Georgia. Two tornadoes were confirmed with this event in northwest Georgia on the 25th, including an EF1 tornado in southern Dade County.

These tornadoes were part of a quasi-linear convective system (QLCS) that moved across north Georgia during the early morning hours.

Doppler velocity and radar reflectivity plots are shown in Figures 2 and 3, respectively, for the QLCS about the time the EF1 tornado touched down in Dade County. The complex, linear nature of the system is very evident, with the bowing and velocity couplet associated with the tornadic storm also easily seen.

Two cells were examined from this event, the cell responsible for the EF1 tornado and a second cell that demonstrated a very prominent mesocyclonic signature but did not result in a confirmed tornado.

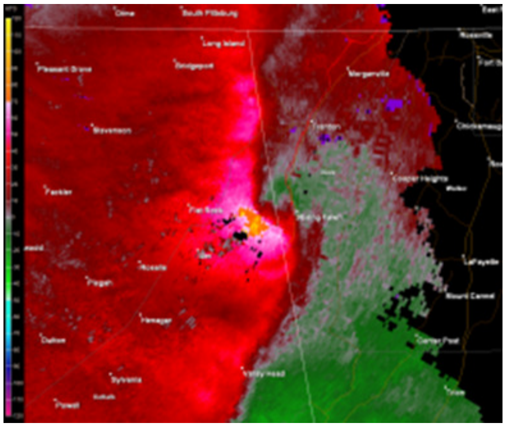


Figure 2. Doppler velocity plot for 25 October 2010, EF1 storm in Dade County, Georgia

Doppler and Reflectivity plots

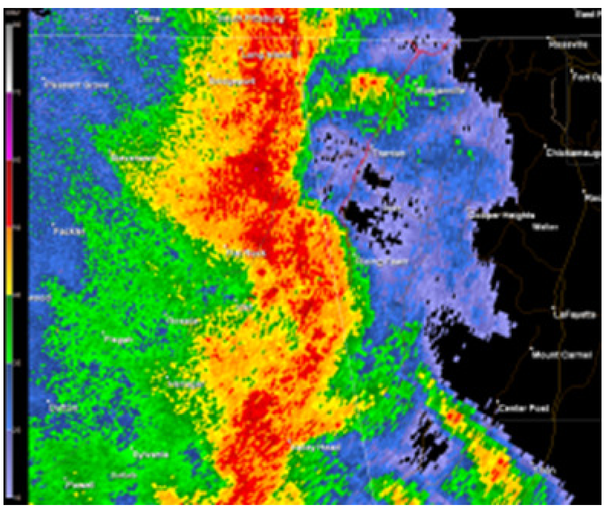


Figure 3. Reflectivity plot from 25 October 2010, Dade County Tornado

3.2 First QLCS Example - Cell #1

The first cell examined for this event was responsible for the EF1 tornado in Dade County. The four mile path of EF1 tornado is contained within nearly 100 miles of cell track produced by the SCIT routine. Figures 4 and 5 show the core and unique area tracks, respectively, for cell #1. For each figure, small ovals indicate the tracked centers of the cell at successive NEXRAD scans. The colored areas surrounding the centers show the areal extent of the core and unique areas. Small inverted triangles are located at the reported touchdown points of the tornado. The tornado track is seen to be located within both the core and unique areas of this cell.

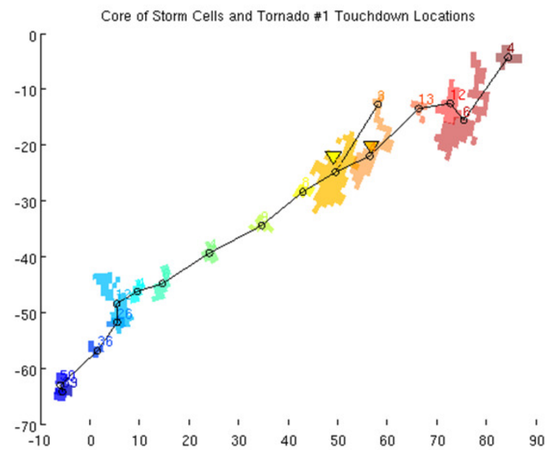


Figure 4. 25 October 2010 - Cell #1 core track and touchdown points

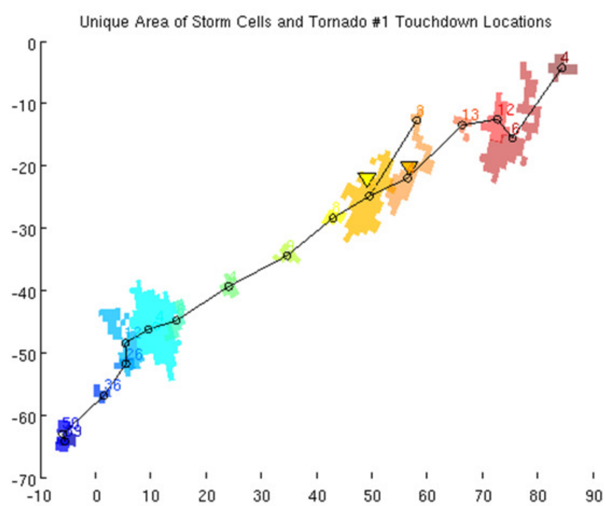


Figure 5 25 October 1020 - Cell #1 unique area track and tornado touchdowns

Lightning rates were examined for all time windows of 1, 3 and 5 minutes around the NEXRAD scan times, as well as for buffer areas

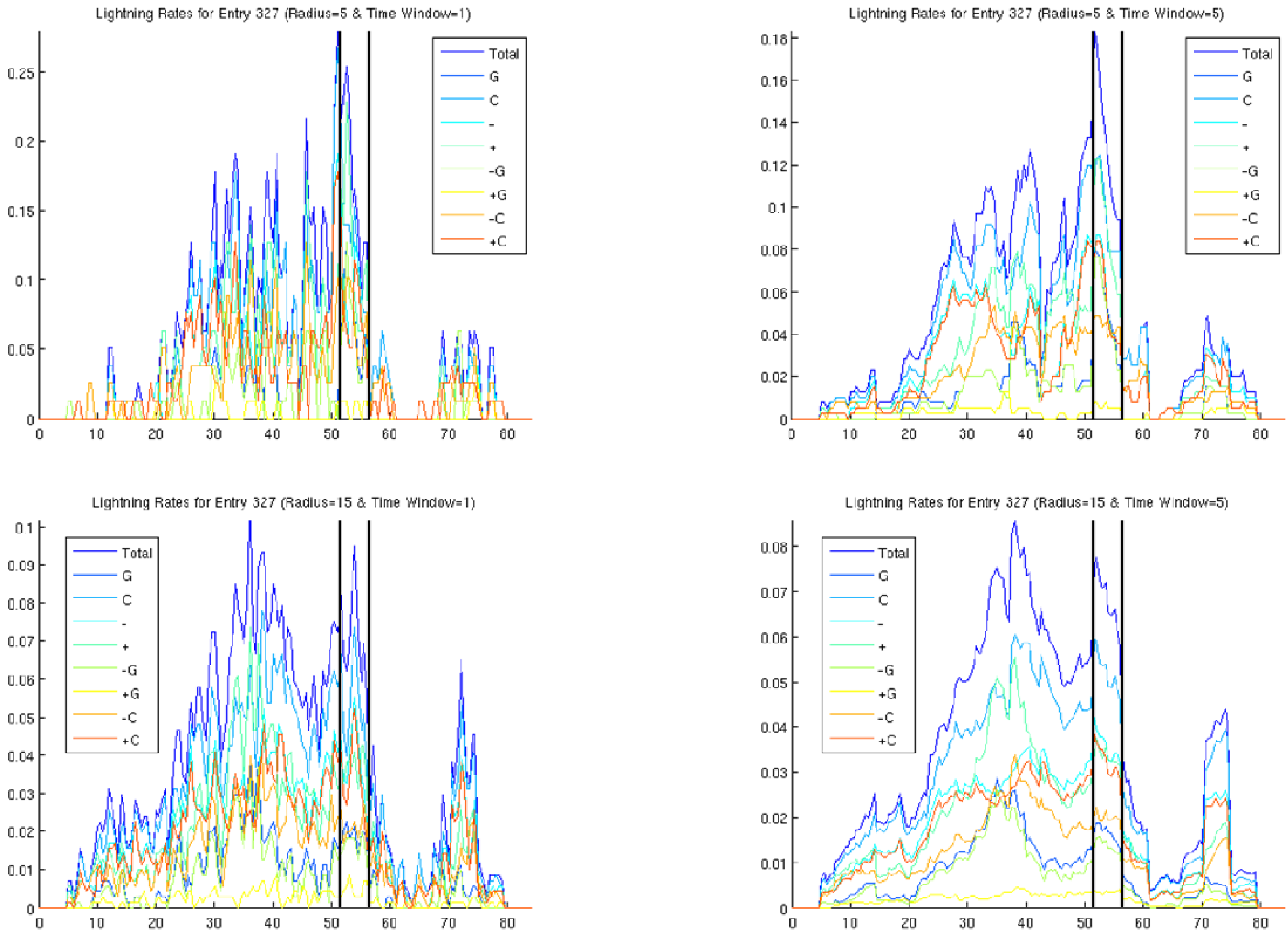


Figure 6. Lightning flash rate plots for cell #1 on 25 October 2010. Each plot uses different values of spacial buffering and time windowing.

of 5, 10 and 15 km. These results can be compared in Figure 6. The use of a small time window makes the plots very noisy when compared with a 5 minute moving average. The choice between a large, 15 km, spacial average and a smaller, 5 km average is less clear. It is likely better to use the smaller spacial average in this QLCS case to avoid contamination of the data by lightning flashes associated with the many nearby cells in the QLCS. Using a 5 minute time windows and a 5 km buffer, a clear lightning jump is indicated during the period associated with the tornado touchdown, with a subsequent reduction after dissipation.

3.3 Second QLCS Example - Cell #3

Another cell involved in the QLCS on October 25 contained a very prominent mesocylone signature in the Doppler plots but never was associated with spotter reports or other indications which would trigger a tornado warning. The prominent Doppler signature indicates that the storm did reach the significantly severe levels. The cell was tracked for nearly 90 miles across the state, as is shown in the core track shown in Figure 7. A corresponding unique area track is provided in Figure 8.

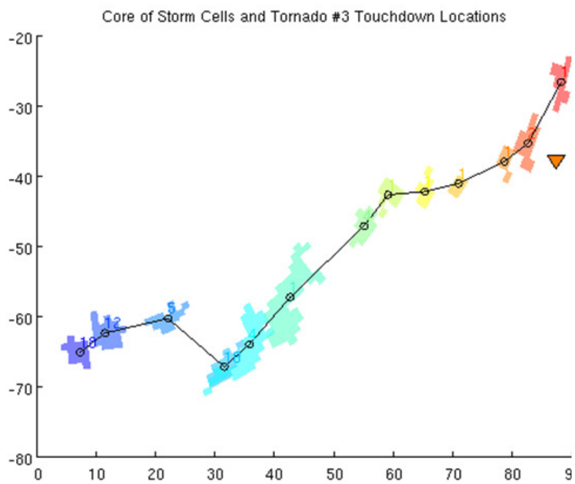


Figure 7 October 25, 2010, Cell #3 core track and possible touchdown

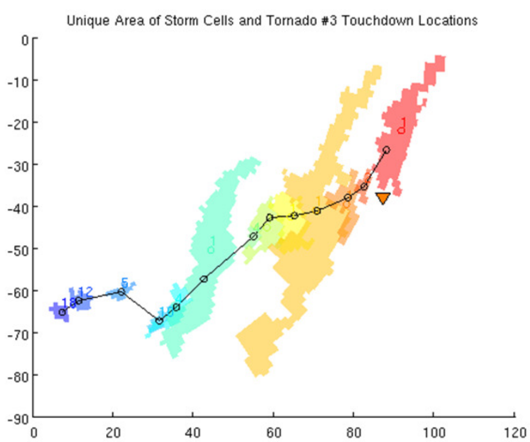


Figure 8. 25 Oct 2010, Cell #3 unique area track and possible tornado touchdown

The time when the mesocyclonic circulation was most prominent is shown in these plots using an inverted triangle. Examination of the total lightning trends for this cell show a large lightning jump coincident with this intensification of the circulation, lending more credence to a possible tornadic event occurring at that time.

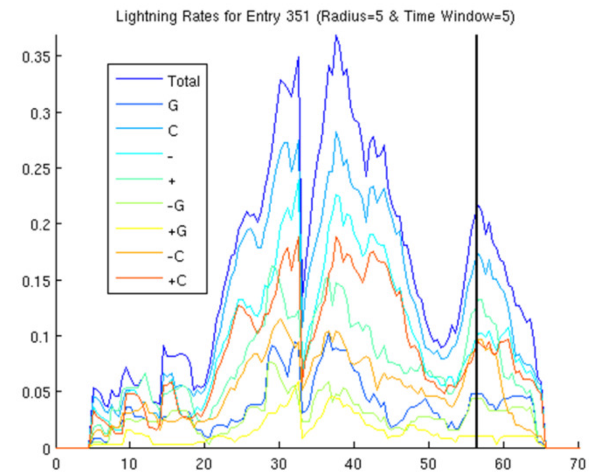


Figure 9 October 25 2010 Cell #3 Lightning Trends

Case 2: Super Cells

A contrasting case involving an outbreak of tornado producing supercells during the evening and night of 18-19 February 2009 was also examined to determine if the SCIT algorithm was robust for this contrasting type of event. This also allowed a comparison of the optimum tuning parameters used for QLCS versus supercell outbreaks.

4.1 Synoptics and Overview

A strong cold front accompanied a deep negatively tilted upper trough through the eastern US from the 18th into the 19th. An unseasonably warm and unstable air mass developed in advance of the front during the late afternoon and early evening as warm, moist air rode northward on a strong low-level jet. Afternoon temperatures in the 70s and dew points in the 60s, combined with strong shear and moderate instability, resulted in the development of numerous supercell thunderstorms.

As a result of the development of these supercells, ten tornadoes, ranging in scale from EF0 to EF3, were confirmed in the state of Georgia. A death was attributed to the EF3 tornado, along several injuries and millions of dollars of damage.

Figure 10 depicts the line of supercells transiting the state of Georgia. The farthest cell to the east (right) contained the deadly EF3 tornado.

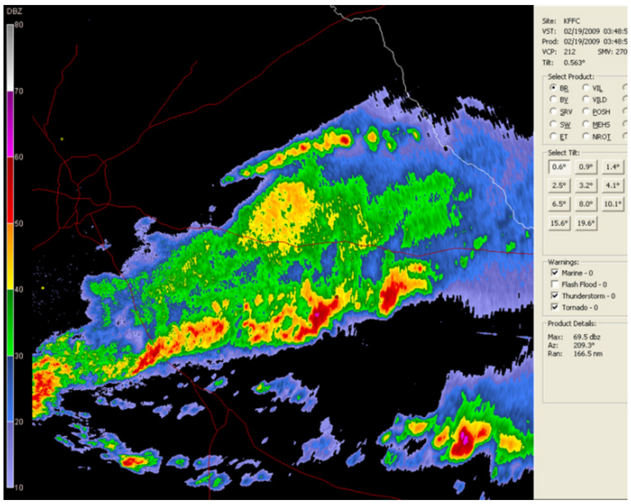


Figure 10 Reflectivity from 18-19 Feb supercell outbreak

The extensive are affected by the supercell ouitbreak of 18-19 February 2009 is shown in Figure 11.

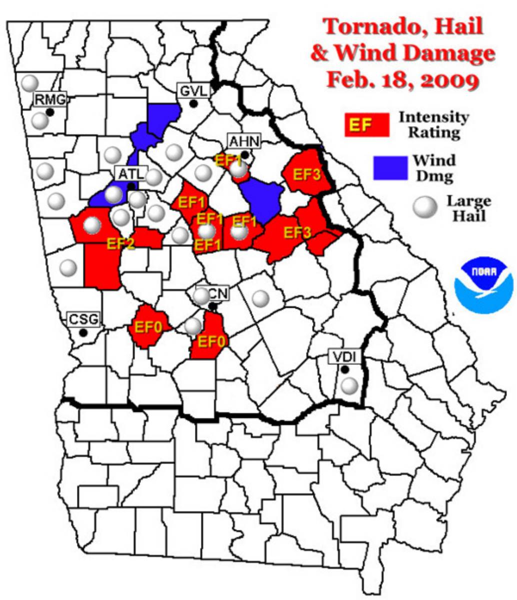


Figure 11 Tornado, hail and wind damage from 18-19 Feb supercell outbreak

4.2 First Supercell Example - Cell #2

The cell identified in the study of the February 2009 supercell event as “cell #2”, was tracked over a distance of over 300 km. It produced an EF1 tornado about 2/3 of the way through the track shown in Figure 12 below. A second EF3 tornado was produced later, near the end of the track.

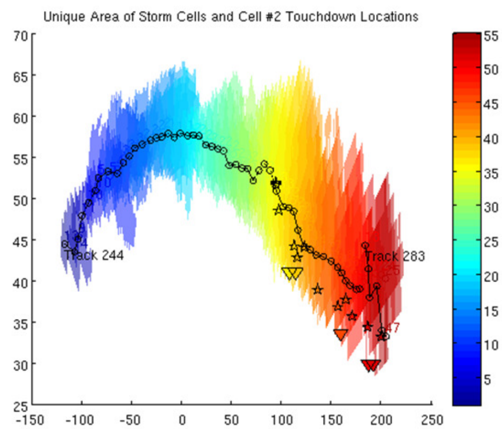


Figure 12 Unique area for cell #2, Feb 18-19 supercell outbreak

An added feature on Figure 12 is a hand-plotted track, depicted as a series of stars on the plot. Once again, the DBSCAN SCIT algorithm can be seen, both by its agreement with the hand-plotted track and by the agreement with the surveyed locations of the tornado touchdown points, to track the supercell structure very well.

Figures 13 and 14 show lightning trends associated with this particular cell. Figure 13 shows trends determined using small time (1 minute) and small spacial (5 km) windows, while Figure 14 shows trends determined using larger windows of 5 minutes and 15 km. Once again, the short, one minute time windows are noisier than desired. In contrast to the QLCS case, a larger spacial window seems to enhance the trends seen for the supercell case. This is sensible when considering that the supercells are much more isolated than the embedded cells found in the QLCS.

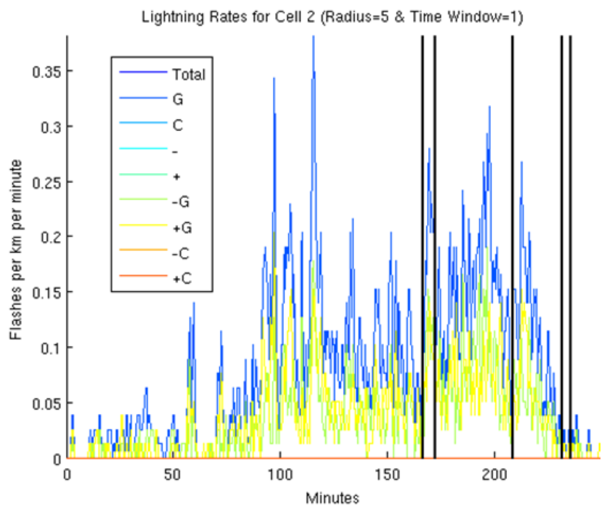


Figure 13 Lightning rate for cell #2, 18-19 Feb. using small radius and short time interval

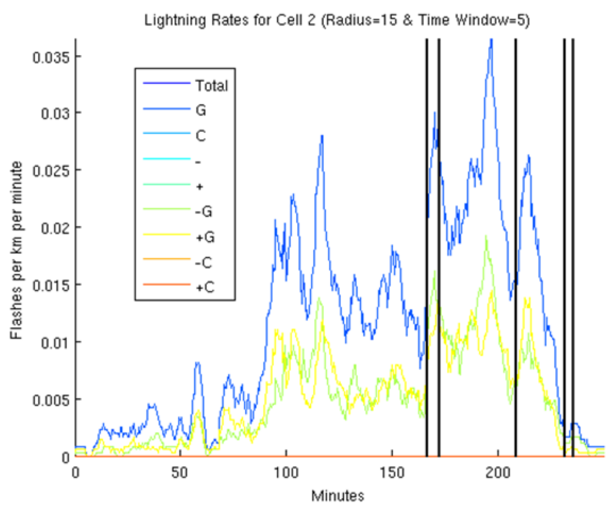


Figure 14 Lightning rate for cell #2, 18-19 Feb using large radius and long time window

The trends in total lightning for this cell show several periods of increasing flash rate, the first coincident with the EF1 tornado and the second preceding the EF3 tornado.

4.3 Second Supercell Example - Cell #5

A second cell examined for the supercell outbreak, labeled cell #5 in the analysis, also produced two tornadoes and had an exceptionally long track. The second tornado depicted in the unique area track in Figure 15 was the EF3 that produced a fatality. The SCIT provided track is, again, shown to be in good agreement both with the hand-drawn track and the surveyed tornado touchdown points.

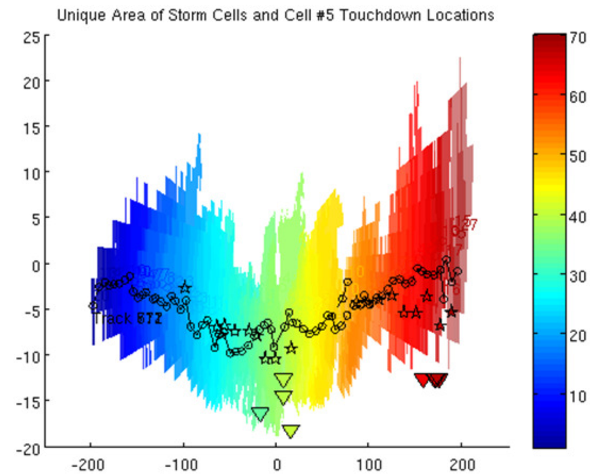


Figure 15 Unique area track for cell #5, 18-19 Feb supercell outbreak

The lightning trends for this second supercell case indicate potential lightning jumps prior to the touchdown of both the first and second tornadoes. The trend for the second, stronger, EF3 tornado is not as pronounced as the trend prior to touchdown of the first tornado, indicating that additional parameters are important in determining the potential for tornadic activity.

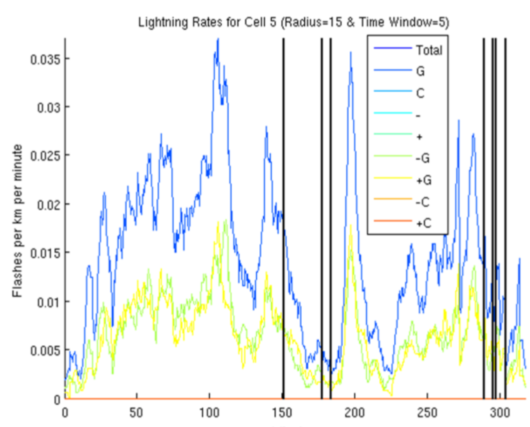


Figure 16 Lightning rate for cell #5, 18-19 Feb supercell outbreak using large radius and long time window

Conclusions and Future Work

The GTRI DBSCAN SCIT algorithm worked very well for both QLCS and isolated supercell cases in both identifying and tracking cells for study. A longer, five minute time window was useful in both cases to smooth out the trends in lightning rate. Different choices of spacial averaging were useful depending on the storm type. The complex embedded cellular structure of the QLCS lent itself better to a smaller spacial buffer choice than the isolated supercell cases.

Another conclusion to be found in this study is that gaining information on the development and severity of a storm solely on the basis of flash rate trends may be difficult. The application of this type of tracking and association method should allow other parameters, such as vertically integrated liquid (VIL), the height of maximum radar reflectivity, or any number of dual-pol parameters, to also be associated in time and space with individual cells. The use of these parameters, in combination with total lightning parameters, may well bring more skill to the prediction of severe events.

Finally, it should be noted that there is always a need to look at more null cases, where no severe events take place, to address false alarm ratio (FAR) and probability of detection (POD) issues.

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