P 2.3 THE UTILITY OF LIGHTNING JUMPS IN SEVERE THUNDERSTORMS IN THE TENNESSEE VALLEY

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1. Introduction

In the past decade, several studies have shown that rapid increases in total lightning activity (intracloud + cloud-to-ground) have been observed several minutes in advance of the occurrence of severe weather at the ground (Williams et al. 1999, Buechler et al. 2000, Goodman et al. 2005, Gatlin 2006). Termed lightning "jumps", these tremendous increases in total lightning trends can sometimes be another valuable instrument in the warning decision support toolbox. Unfortunately, not all thunderstorms that display this jump in total lightning produce severe weather, moreover, not all thunderstorms that produce severe weather demonstrate significant jumps in total lightning (Williams et al 1999). Optimistically, a positive correlation between lightning jumps and the manifestation of severe weather at the ground have been shown in thunderstorms across the Tennessee Valley (Goodman et al. 2005, Gatlin 2006).

Recent algorithm development has focused on the creation of a functional algorithm that can be applied to current ground detection of total lightning and in the near future, spaceborne detection of total lightning (e.g. the GOES-R Geostationary Lightning Mapper; GLM).

This particular study examines the jump signature proposed by Gatlin (2006), with the aim to test and refine the current jump signature algorithm on a larger database of severe and non-severe thunderstorm cases. The overall goal is to support and develop an operational algorithm for the GLM.

2. Jump Signature Background

Gatlin (2006) proposed the following algorithm to track trends in total flash rate as related to quantitatively identifying lightning jumps. First, the time rate of change of the total flash rate must be calculated, DFRDT.

$$DFRDT = \frac{d}{dt}(TFR) \qquad (1)$$

Eqn. 1 – Calculation of DFRDT. TFR represents the total flash rate for a certain time step.

Initially, Gatlin used 1-minute, 2-minute and 5-minute time steps in his calculation of TFR to assess which time duration would yield the most robust results. He found that the 2-minute time duration worked best because it allowed for higher time resolution while smoothing the data out to allow for better identification of a lightning jump. A DFRDT jump threshold is then determined from the standard deviation of a fixed number of DFRDT samples. In the early stages of development, the standard deviation was determined from 60 minutes worth of data at all three time resolutions. Therefore, if the 2-minute time step was used, the sample number N used in determining the

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standard deviation would be N=30. Gatlin found that this often eliminated smaller jumps that could be correlated to severe weather events, therefore he adopted a moving threshold technique that took the 6 most current DFRDT values to calculate a standard deviation. A jump would then end once the DFRDT value dropped below the weighted mean value which is calculated similarly.

3. Data and Methodology

In this study, Next Generation Weather Radar (NEXRAD) data were retrieved from the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC) in level II format. Four WSR-88D radar sites are primarily used in this study: Hytop, AL (KHTX), Birmingham, AL (KBMX), Columbus AFB, MS (KGWX), and Sterling, VA (KLWX). Radar data were then converted from polar coordinates to Cartesian coordinates using the REORDER software (Oye and Case, 1995), and the data interpolated to a 2 km x 2 km x 1 km Cartesian Grid.

Individual thunderstorms were identified and tracked using the Thunderstorm Identification, Tracking, Analysis, and Nowcasting algorithm (TITAN) developed by Dixon and Wiener (1993). When a convective cell was identified by the tracking program, it is assigned a center based on latitude and longitude coordinates, and a major and minor axis.

Previous lightning jump studies have dealt with isolated thunderstorms, which are somewhat easier to track and identify. One of the objectives of this study is to apply the jump theory to all types of convection (i.e. isolated storms, squall lines, lines with embedded supercells, tropical systems), therefore a technique has been developed based on a previous study to isolate convective cells. Using a theory developed in Vincent and Carey (2003), convective cells are identified by TITAN using a 35 dBZ threshold at the height of the -15ºC isotherm; a temperature consistent with the location of the thunderstorm charging region. For example, if the -15ºC isotherm is located near 6 km, then individual storm cells would be identified at this level. Balloon soundings from Nashville, TN and Birmingham, AL, are used to interpolate a profile for Huntsville, AL, since until the past year there was not a daily sounding available. The soundings closest to the thunderstorm event are used for the interpolation, and the -15ºC isotherm height is rounded to the nearest kilometer.

For a description of the North Alabama Lightning Mapping Array (NALMA) see Koshak et al. (2004).

Fig. 1 - North Alabama Lightning Mapping Array antenna locations across North Central AL.

Individual sources detected by the LMA are pieced together into flashes using a clustering algorithm developed by E.W.

McCaul (McCaul et al. 2002) to rebuild the individual lightning flashes.

Two additional cases in this study have also been taken from the Washington D.C. Lightning Mapping Array (DCLMA). This lightning detection system operates similar to the one in Northern Alabama, however, it consists of only 8 receiving stations. Although the flash clustering algorithm used in the DCLMA is not exactly the same as the one for Northern Alabama, the cases are still useful in demonstrating that jump signatures occur elsewhere in the US. The overall goal is to be able to use this algorithm over the entire coverage domain of the GOES-R GLM is in place, therefore, exploring total lightning trends in other portions of the country and other storm regimes is important.

The National Lightning and Detection Network (NLDN) (Cummins et al. 1998) is used for the detection of cloud-to-ground flashes. The NLDN has a detection efficiency of 90 %. A +/- 10 kA threshold is applied to the data to eliminate intracloud lightning noise (Cummins et al. 1998, Boccippio et al. 2001), which is believed to contaminate up to 5% of the total dataset.

To summarize the methodology, TITAN first identifies and tracks convective cells using the 35 dBZ threshold at the height of -15ºC throughout their lifetime. The cell information is then used to identify lightning flashes (both total lighting and cloud-to-ground) that occur within the bounds of the cell between consecutive volume scans. Only total flashes that initiate within the bounds of the cell are counted. Advection of the convective cell is accounted for using an averaging technique that is applied to the storm information in consecutive volume scans. Occasionally, a handful of flashes are missed during the storms entire lifetime, however, this study is interested in the trend in lightning and not the exact number of flashes associated with a convective cell. Therefore, if a handful of flashes are missed, this should not have a major effect in the overall trend in total flash rate for a storm. Flash rates for total lightning and cloud-to-ground lightning are placed into one minute bins, and furthermore, cloud-to-ground data is separated by polarity to determine positive and negative polarity ratios.

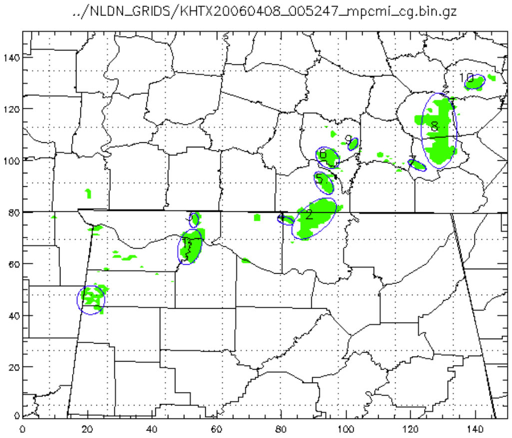

Fig. 2 – An example of the TITAN tracking algorithm. This example is from KHTX on April 8, 2006 at 0052 UTC across Northern AL and South Central TN, where several supercells were imbedded within a larger convective line. Using the height of the -15ºC isotherm at 6 km and reflectivities of 35 dBZ and greater allows for the identification of more vigorous convective cells within the convective line.

So far, very little modification to the Gatlin method has been done because new modifications are in the developmental phase. One such modification, a 30 minute moving standard deviation, was been applied to several of the cases, however, it was not proven to increase the effective use of total lightning data in severe thunderstorms. Other modifications in the works will be outline in the future work section below. For now, case days were analyzed using the Gatlin method and the 30 minute standard deviation method just to identify larger jumps in DFRDT prior to severe weather occurrence.

4. Preliminary Results

Seven case study days, totaling 14 convective cells show that there are significant jumps in lightning activity and DFRDT prior to the onset of severe weather at the surface. Most correspond to hail events, but several have been associated with tornadic events. DFRDT jump lead times on severe weather events range from a few minutes to as long as 20 minutes in advance. Figure 4 shows one case, where three distinct DFRDT jumps occur followed by severe weather being observed at the ground.

However, not all cases that have been examined show such positive results. One severe weather event from June 19, 2007 in Northern Alabama contained very little lightning (total and cloud-to-ground) prior to the production of a small EF-0 tornado in Lawrence Co., AL. Additionally, when cells split or merge, it has been difficult in determining what flash values should be assigned to each cell. For the most part, identifying cells at the -15ºC isotherm does a good job of isolating convective cells within a larger line, however, on occasion the lines are very intense, and individual cells are not able to be pulled out.

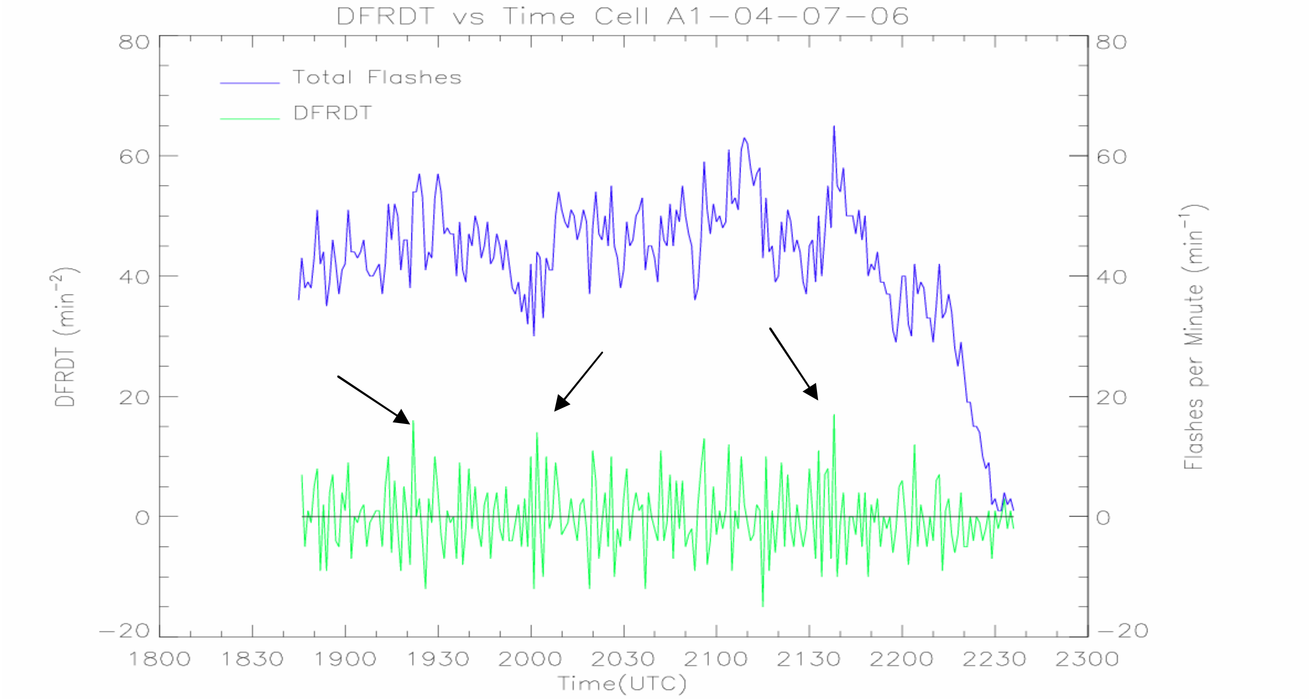

Fig. 4 - A plot of total flash rate (blue) and DFRDT (green) from a tornadic cell on April 7, 2006 that tracked across South Central TN. The largest spikes in DFRDT (indicated by arrows) can be seen around 1930 UTC, 2000 UTC and 2140 UTC, and all correspond to severe weather reported at the ground (hail (1943 UTC), tornado (2016 UTC), tornado (2156 UTC).

5. Future Work

In its present state the Gatlin technique is still not universally applicable and it is difficult at times to assign one specific lightning jump to a severe weather event. The next stage of this research will be to apply the methodology discussed herein to non-severe thunderstorms from several areas of the country. This smaller portion of the study will demonstrate how lightning, and in particular, the DFRDT in ordinary convection behaves, and allow the ability to filter severe from non severe events. Once this part of the study is complete, modification of the lightning and DFRDT data can be done to help better identify when a storm may become severe. Finally, normalizing the DFRDT data to pull out the largest jumps in a given period will further enhance the effectiveness of the DFRDT algorithm.

Also, lightning trends in these storms will be compared to trends in the more traditional severe weather parameters observed on radar, which will allow for the possible correlation between jumps in lightning activity and severe weather signatures.

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