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Low Topped Convection and Total Lightning Observations from North Alabama

Geoffrey T. Stano[1], Brian Carcione[2], Kristopher D. White[3], and Christopher J. Schultz[4]

[1]NASA SPoRT / ENSCO, Inc., Huntsville, Alabama

[2]NOAA / National Weather Service, Huntsville, Alabama

[3]NASA SPoRT / NOAA / National Weather Service, Huntsville, Alabama

[4]NASA Marshall Space Flight Center, Huntsville, Alabama

ABSTRACT

Total lightning observations from the North Alabama Lightning Mapping Array (NALMA) have been used in operations with the Huntsville National Weather Service office since 2003. In a partnership with NASA's Short-term Prediction Research and Transition (SPoRT) Center, observations from this very high frequency (VHF) detection network are used for several activities. Predominantly, the NALMA data are used to enhance the situational awareness of forecasters which in turn leads to a better analysis of storm intensification and improved severe thunderstorm and tornado warnings. Total lightning observations also are used in lightning safety situations aiding with airport weather warnings alerting to the threat of imminent lightning activity.

The training that SPoRT provides on the use of NALMA data, as well as data available from other networks, emphasizes lightning jumps as precursors to severe weather. Specifically, a lightning jump is a rapid increase in total lightning activity, which is strongly related to the updraft strength of the thunderstorm. This is used to great effect in numerous severe weather warning events. However, lightning jumps do not always precede severe weather manifestation, and there are several notable cases where this has not occurred. In particular are events from 6 May 2009 and 21 January 2010. In each case a thunderstorm produced an EF-2 rated tornado with very little total lightning observed. Both cases occurred just outside (6 May) or in (21 January) Huntsville, which is in the heart of the NALMA network and therefore had no detection efficiency issues. Analysis of these two events demonstrates that these were low-topped thunderstorms. Here the lightning production was limited as the updraft did not extend into the mixed phased region where charging primarily occurs. This presentation will take a preliminary look at the two low-topped convection events just mentioned, along with several other cases that serve as a "null" set of data for using total lightning as a precursor to severe weather. Future research will investigate whether limited lightning production is commonly observed with low-topped convection, or if these are special cases.

1. Introduction

The Short-term Prediction Research and Transition (SPoRT) Center (Darden et al. 2002; Goodman et al. 2004) (http://weather.msfs.nasa.gov/sport) has been collaborating with partner Weather Forecast Offices (WFOs) since 2003. This effort has been to transition unique NASA data sets to operations to enhance the National Weather Service's (NWS) mission of protecting lives and property as well as to demonstrate future capabilities that will be available with the launch of GOES-R. A project that has benefited both of these efforts is the transition of total lightning data (cloud-to-ground and intra-cloud lightning) from ground based lightning mapping arrays (LMAs – Rison et al. 1999; Thomas et al. 2000; 2001; Koshak et al. 2004; Goodman et al. 2005; Krehbiel 2008; MacGorman et al. 2008; Bruning et al. 2011) to collaborative WFOs.

Since the initial transition, total lightning has proven to be a valuable tool in the warning decision environment, especially when compared to cloud-to-ground data alone. Through numerous evaluations and discussions with forecasters, total lightning has been used to improve situational awareness, warning decision support, lightning safety, and providing a lead time on the first cloud-to-ground strike (Bridenstine et al. 2005; Goodman et al. 2005; Demetriades et al. 2008; Nadler et al. 2009; Darden et al. 2010; Stano et al. 2010; MacGorman et al. 2011; Stano 2012; White et al. 2012). This use has primarily focused on the concept of a lightning jump (Schultz et al. 2009; Gatlin and Goodman 2010; Schultz et al. 2011).

Corresponding Author: Dr. Geoffrey T. Stano
NASA SPoRT, ENSCO, Inc.
320 Sparkman Dr., Huntsville, AL 35805
E-mail: geoffrey.stano@nasa.gov

Essentially, forecasters subjectively look for storms that show a rapid increase (decrease) in total lightning and use this as an indicator that an updraft is rapidly intensifying (weakening). Whether done subjectively or as part of the effort to operationalize an objective lightning jump algorithm, the jump signature provides forecasters an additional piece of information that signifies that a thunderstorm is about to strengthen or broach severe thresholds. The jump signature is particularly useful as the total lightning data update every 1 or 2 minutes (depending on the LMA in question), which is faster than a radar volume scan update time.

Thanks to training and a strong collaborative partnership between SPoRT and its partner WFOs there is a strong core of forecasters who now are well versed in using and interpreting total lightning observations. This is leading the partnership to investigate more complex issues with respect to total lightning. Two in particular are expanding the use of these data for lightning safety and exploring cases when the concept of a lightning jump does not work. In other words, what happens when severe weather occurs and no lightning jump is observed? It is this later question that will be discussed in this paper.

Section 2 will discuss a traditional lightning jump example, which makes up the vast majority of cases, from the severe weather event on 2 March 2012 in northern Alabama. Section 3 investigates three separate cases (21 January 2010, 6 May 2009, and 10 December 2008) where an EF-2 tornado was observed in each case, but no corresponding lightning jump was observed. Section 4 will formally compare these null events to the traditional event while Section 5 will provide the authors' conclusions.

2. Traditional Lightning Jump Events

Before focusing on the null events, it is beneficial to discuss what is driving lightning production and generating a lightning jump. Total lightning production is driven by the strength of a storm's updraft, which is the main mechanism responsible for charging within the storm. This relationship is outlined well in Schultz et al. (2009) and summarized here. Initially, this connection was shown in Workman and Reynolds (1949) where the amount of lightning produced was closely tied to the updraft evolution and the appearance of an ice phase. Later, the relationship between storm depth and the amount of lightning produced was determined to be non-linear (Vonnegut 1963; Williams 1985; and Boccippio 2002). This indicated that storms with strong updrafts have a greater potential to produce lightning. Carey and Rutledge (1996; 2000) and Petersen et al. (2005) provided further evidence linking precipitation ice mass to lightning occurrence while Deierling (2006) linked the ice mass and updraft to lightning occurrence. Combined, these studies present a strong relation between the microphysical and dynamical development of a thunderstorm to lightning activity. This has led to the concept of a lightning jump (Schultz et al. 2009; Gatlin and Goodman 2010; Schultz et al. 2011), that serves as precursory evidence that a given thunderstorm is about to strengthen or become severe. Overall, the ability to observe a lightning jump is made possible through the use of LMAs and the future Geostationary Lightning Mapper (GLM – Christian et al. 1992; 2006) as these observe total lightning and not just cloud-to-ground lightning strikes.

With this background, the next step is to examine a traditional lightning jump example. For this paper, the example comes from 2 March 2012 which produced severe hail and an EF-2 tornado that morning near Huntsville, Alabama. Prior to this, soundings observed a favorable environment for severe weather. The CAPE was analyzed to be ~1000 J / kg while the helicity was 350 m^2/s^2 in the lowest kilometer. Combined with available moisture, this environment was conducive to supercells and potential tornadoes. Additionally, soundings observed the -10°C and -20°C isotherms at ~4575 (15 kft) and 6100 (20 kft) m, respectively. These observations were acquired from the Birmingham, Alabama and Nashville, Tennessee soundings as well as RUC analyses.

Figure 1 (first image from slide 5) starts with a display from AWIPS with the total lightning source density display (for the past 2 minutes) and the 3.4° radar reflectivity at 1442 UTC from the KHTX radar. The 3.4° tilt was chosen as this was closest to observing the -20°C isotherm level. At this time, the total lightning source density is minimal with values not exceeding 35 sources in any 2×2 km grid box for the past two minutes. When the source densities are compared with the 3.4° radar reflectivity, it is observed that the reflectivity values are barely reaching 40 dBZ. This currently fits the physical, conceptual model of lightning production. At 1442 UTC, the updraft is reaching the mixed phase region of this storm, but not significantly. This is reflected in the source density values as lightning is observed, but not enough to consider this as a potential severe weather threat.

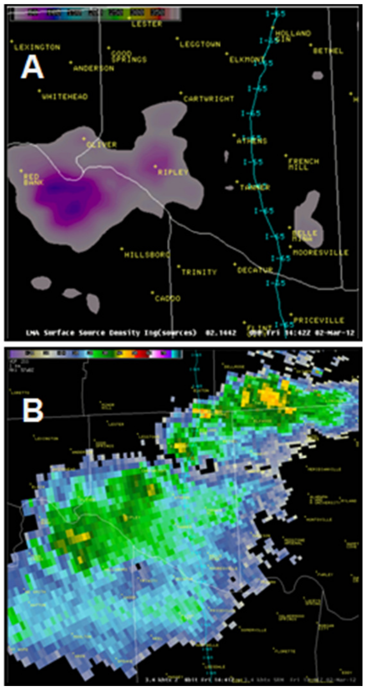

Figure 1: The two minute, 2×2 km resolution source density product (A) and the 3.4° radar reflectivity (B) that most closely corresponds with the -20°C isotherm at 1442 UTC on 2 March 2012.

The picture begins to change in Figure 2. Here, the total lightning source densities have rapidly increased to over 400 sources at 1450 UTC. This rapid increase is seen two minutes before the 3.4° radar reflectivity is observed to have 58 dBZ near -20°C at 1452 UTC. This illustrates, again, our conceptual model as the lightning activity has significantly increased as the updraft intensifies into the mixed phase region. Furthermore, this illustrates a powerful advantage of total lightning as it updates more rapidly than the radar volume scans. Also, the lightning jump occurred ahead of the severe hail that was observed while no three body scatter was detected by radar. At this time, the forecaster on shift saw this lightning jump occur, and combined with other features, concluded that this storm was about to become severe. This provided a 7 minute lead time on the first severe hail reports and a 19 minute lead time on the formation of the tornado that was eventually rated an EF-3.

To further investigate this event, a radar reflectivity cross section was taken at 1506 UTC four minutes before the initial touchdown of the tornado (Figure 3). Here, a 58 dBZ core is observed extending to 5500 m with reflectivities of 40 dBZ extending through 9700 m. Overall, this continues to demonstrate the relationship between total lightning production and the strength of the updraft in the mixed phase region and provides a physical explanation for why a lightning jump is observed ahead of a severe weather event.

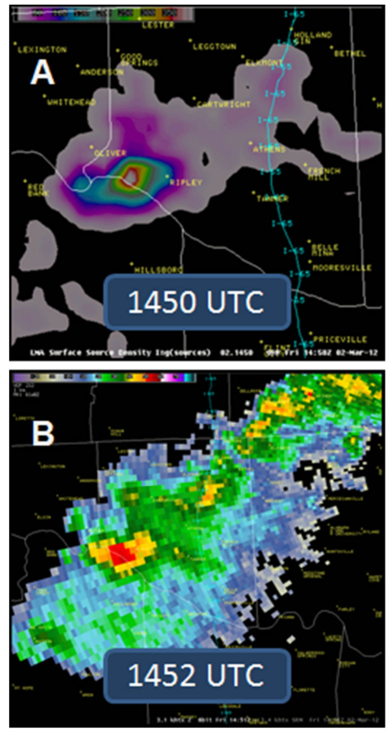

Figure 2: Same as Figure 1, but with the source densities (A) at 1450 UTC and the 3.4° radar reflectivity (B) at 1452 UTC on 2 March 2012.

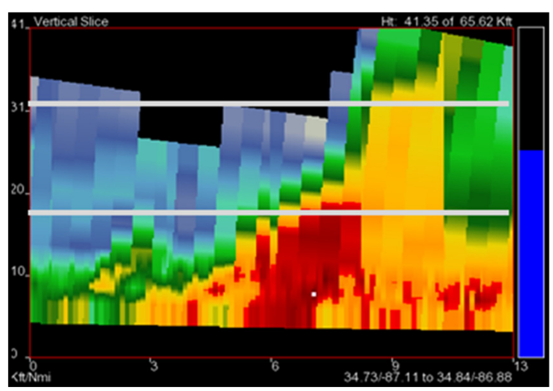

Figure 3: Radar reflectivity vertical cross section taken at 1506 UTC on 2 March 2012 four minutes prior to the tornado touchdown. The lower bar is the -10°C isotherm level while the upper bar is the -20°C isotherm level.

3. Null Events

The 2 March 2012 event, with a single isolated cell, is a good example to show the physical relationship between total lightning and the decision support tool most used by forecasters, radar. The question now raised is this. Is this feature always true? The definitive answer is no. Situations arise, such as landfalling tropical systems to low topped convection, where severe weather occurs without the lightning production to generate a lightning jump. Currently, total lightning use is limited to Weather Forecast Offices (WFOs) that have access to LMAs. However, this is rapidly changing with the introduction of the Earth Networks lightning detection systems and the future launch of the GLM aboard GOES-R. In other words, it is vital to ensure that the operational community sees these caveats to the use of total lightning by linking total lightning to their physical conceptual model. The SPoRT program is developing training to address this with our partner WFOs. This paper addresses low topped convection.

a. 21 January 2010

The first "null" example to examine was from 21 January 2010. This was a well forecast event with favorable conditions for severe weather. One storm that day generated an EF-2 tornado in downtown Huntsville, Alabama, which is in the heart of the NALMA network. However, no lightning jump was observed.

For this event, the Storm Prediction Center had issued a slight risk for the region with a 5% probability of tornadoes. Surface temperatures were in the upper 60s while the dew point was in the upper 50s. At 1700 UTC, the sounding taken at Redstone Arsenal just outside of Huntsville, Alabama indicated very weak CAPE of ~100 J / kg. Meanwhile, the helicity in the lowest 1 km was 231 m^2/s^2. The -10°C and -20°C isotherms were observed at ~4500 (14.9 kft) and 6100 (20 kft) m, respectively.

Figure 4 shows a four-panel display from AWIPS at 2236 UTC. At this time only a small cluster of storms is observed moving to the east-northeast, moving out of Limestone County and into Madison County towards Huntsville, Alabama. No significant features were observed at this time in the radar storm relative velocity. At the same time, no cloud-to-ground strikes were observed and the total lightning source density values were no more than 14 sources, which were very minimal.

The scene was little changed by 2256 UTC 20 minutes later (Figure 5). A strong reflectivity core was observed. The lightning observations were less than convincing as only a single cloud-to-ground strike was observed at this time and the total lightning source densities only reached 20 sources. If a forecaster were using total lightning only and not including radar, the observations would suggest that this storm was not a severe weather threat.

By 2316 UTC (Figure 6), the total lightning observations were unchanged. Conversely, the radar reflectivity was indicating a potential hook echo. The storm relative velocity was beginning to observe a weak couplet in this storm. Eventually, an EF-2 tornado struck downtown Huntsville, Alabama and was never preceded by a lightning jump. The following figures will discuss the physical reasoning for this.

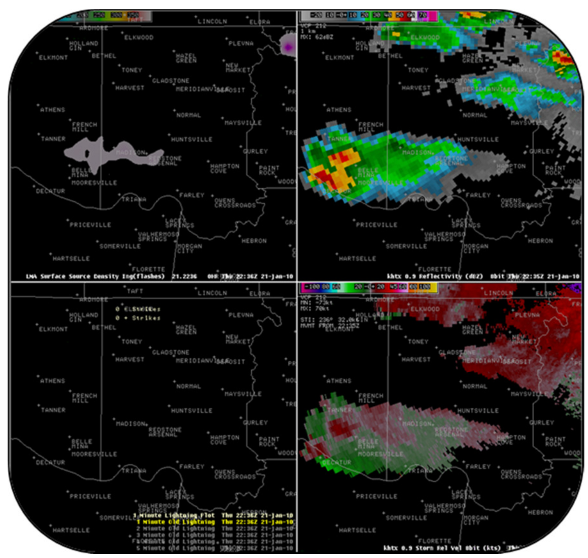

Figure 4: An AWIPS four panel display of total lightning source densities (upper left), National Lightning Detection Network data (lower left), radar reflectivity (upper right), and radar storm relative velocity (lower right) at 2236 UTC on 21 January 2010.

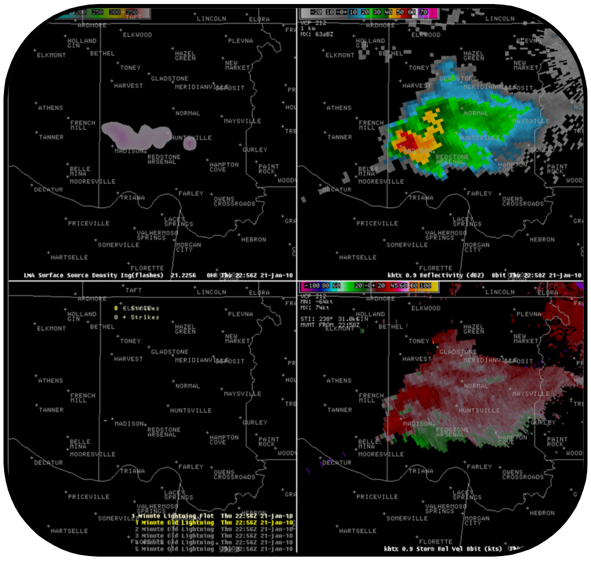

Figure 5: Same as Figure 4, but at 2256 UTC.

A radar reflectivity range height image was taken at 2317 UTC (Figure 7). Note the differences between this example and the one taken from 2 March 2012 (Figure 3). Unlike the March 2012 example, this particular storm cell was extremely shallow. The top of the storm barely reached 7900 m. The main updraft was about 45 dBZ in the mixed phase region. However, the greatest reflectivity values were well below 3600 m and the mixed phase region. Figure 8 shows a corresponding CAPPI slice roughly taken at the -20℃ isotherm level at 6100 m. Compared to the 2 March 2012 case (Figure 2), this event had a much weaker storm core and thus less charging to produce lightning.

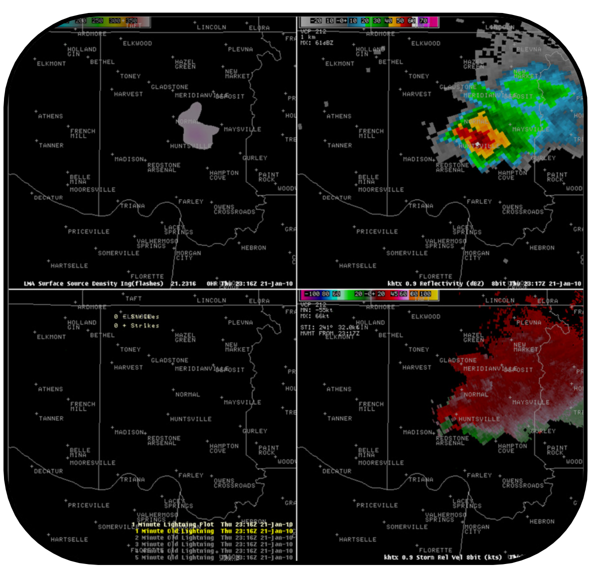

Figure 6: Same as Figure 4, but at 2316 UTC.

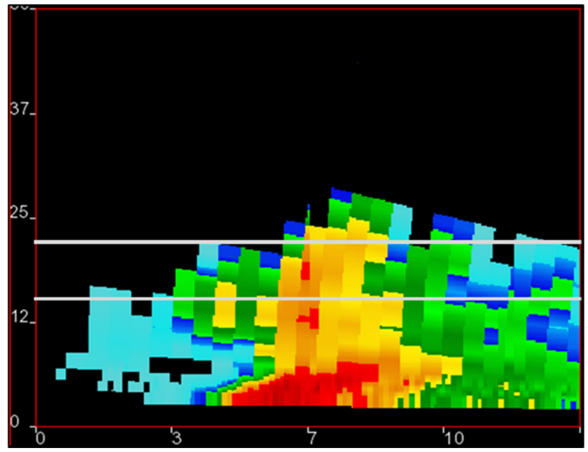

Figure 7: A vertical radar reflectivity cross section at 2317 UTC on 21 January 2010. The lower bar is the -10℃ isotherm level and the upper bar is the -20℃ isotherm level. These levels were obtained through both soundings and proximity RUC soundings.

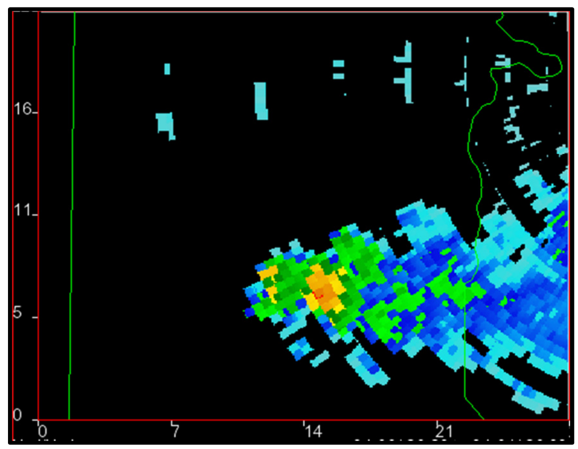

Figure 8: A Four-Dimensional Storm Cell Investigator (FSI) CAPPI slice that corresponds roughly with the -20℃ isotherm, roughly at 6100 m (20 kft) at 2317 UTC on 21 January 2010.

b. 10 December 2008

Another case to examine occurred on 10 December 2008. Unlike the 21 January example, this event was from a quasi-linear convective system and not an isolated, mini-supercell. However, there were some similarities. Analyses observed that the CAPE was ~115 J / kg. The helicity was observed to be 450 m^2/s^2 in the lowest three kilometers, again indicating a highly sheared environment. The -10℃ and -20℃ isotherms were observed at ~5200 (17.1 kft) and 6700 (21.9 kft) m.

A time series of the total lightning observations for this example (Figure 9) had no indication that a rapid increase had occurred.

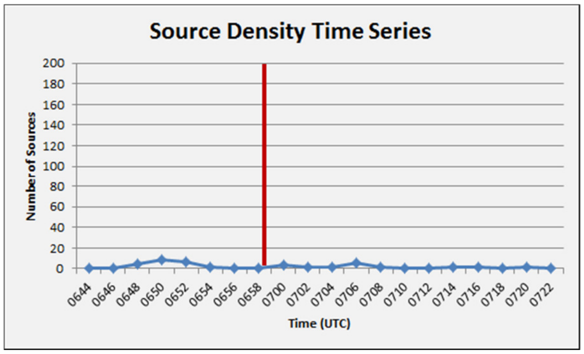

Figure 9: A time series plot of total lightning source densities for the tornadic cell that occurred on 10 December 2008.

Had total lightning been the only source of information, there was no indication that severe weather was imminent. Figure 10 was taken at 0658 UTC, two minutes prior to the touchdown of an EF-2 rated tornado and shows the AWIPS four panel display while Figure 11 is the corresponding reflectivity cross section. The

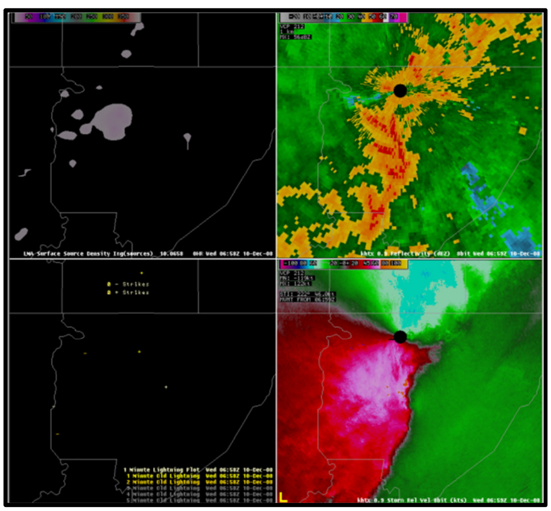

Figure 10: AWIPS four panel display at 0658 UTC (2 minutes before touchdown) on 10 December 2008. Displayed are the lightning source densities (upper left), National Lightning Detection Network cloud-to-ground strikes (lower left), radar reflectivity (upper right), and radar storm relative motion (lower right).

radar reflectivity indicated a notch in the line that corresponded with a developing couplet in the storm relative motion. The cross section showed the highly sheared nature of these storms. Also, it showed that while there were strong reflectivity values in the storm, the cores were barely reaching, let alone exceeding, the -10℃ isotherm level at 5200 m. With the updrafts not even reaching the mixed phase region, there was almost no mechanism to generate charging for lightning activity. These trends continued after the tornado touched down at 0700 UTC (not shown).

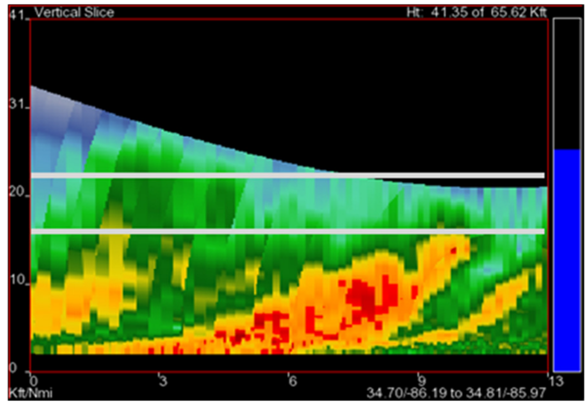

Figure 11: A vertical cross section of radar reflectivity at 0658 UTC on 10 December 2008.

c. 6 May 2009

Originally, this presentation was going to be named for cold season trends in total lightning. The two examples above would appear to support that name. However, as additional events were analyzed, it was obvious that this was not a phenomena limited to the cold season. This is demonstrated with the next example taken from 6 May 2009.

The soundings from Birmingham, Nashville, and RUC analyses observed a CAPE of ~700 J/kg while the helicity was 171 m^2/s^2 in the lowest kilometer. Through 3 km the helicity was 287 m^2/s^2. These observations gave this case a CAPE similar to the traditional 2 March 2012 example. However, Figure 12 shows the time series plot of total lightning during the event with red lines representing the tornado touchdown times. The three tornadoes were an EF-1 (1325 UTC), EF-0 (1343 UTC), and EF-2 (1357 UTC). Interestingly, there is a large lightning jump that occurs after the initial touchdown of the EF-2. Finally, the -10℃ and -20℃ isotherms were at ~5090 (16.7 kft) and 7000 (23 kft) m, respectively.

Figure 13 shows the AWIPS display and Figure 14 shows the radar reflectivity cross section just prior to the first tornado at 1324 UTC near Caddo, Alabama. Here, a line of thunderstorms were moving across northern Alabama. Like the 21 January and 10 December events, there was little total lightning in the tornadic cell with values not exceeding 30 sources. The reflectivity cross section observed that the storm core was reaching into the mixed phase region, but not to the extent that was observed in the classic 2 March case seen in Figure 3. Unlike the 21 January and 10 December examples, more significant total lightning values were observed in the line of storms. None were large enough to constitute a lightning jump, but this demonstrates that there was more available charging.

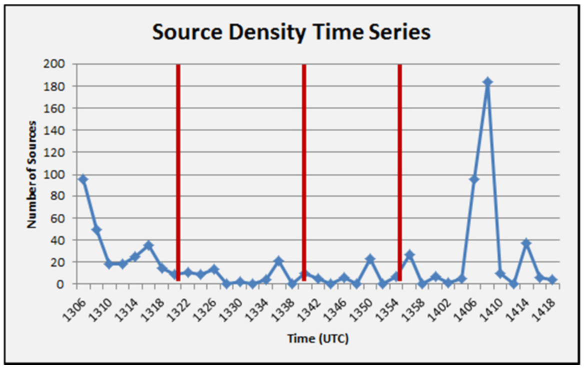

Figure 12: Total lightning source density time series for the three tornadoes that occurred on 6 May 2009.

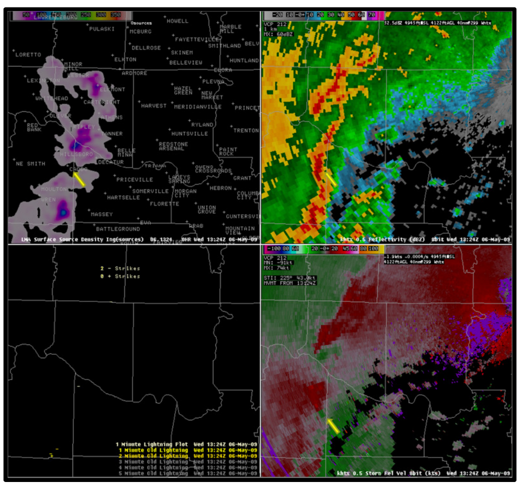

Figure 13: Same as Figure 10, but for 6 May 2009 at 1324 UTC. Arrows indicate the storm in question.

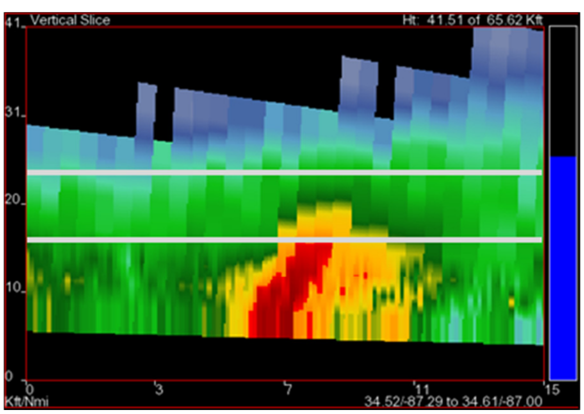

Figure 14: Same as Figure 11, but for 1324 UTC on 6 May 2009.

Figures 15 and 16 show similar displays to Figures 13 and 14, respectively, but now one minute prior to the Decatur, Alabama EF-0 tornado at 1342 UTC. Two features were immediately apparent. First, the cross section shows that the core of the storm greatly weakened. There was no significant updraft in the mixed phase region and the only large reflectivity values were very shallow. This was seen in the weak total lightning source density values for the cell in question, as well as the surrounding cells in the line. The second change was in the line of storms. The line was beginning to break up and appeared to be organizing into discrete cells. This suggested that the convective mode may have been changing.

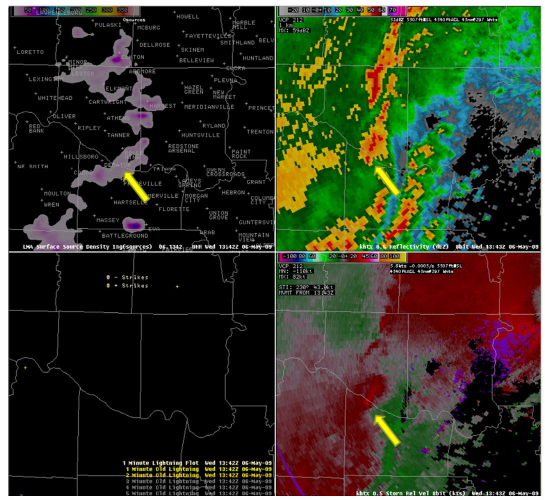

Figure 15: Same as Figure 10, but for 1342 UTC on 6 May 2009. Arrows indicate the storm in question.

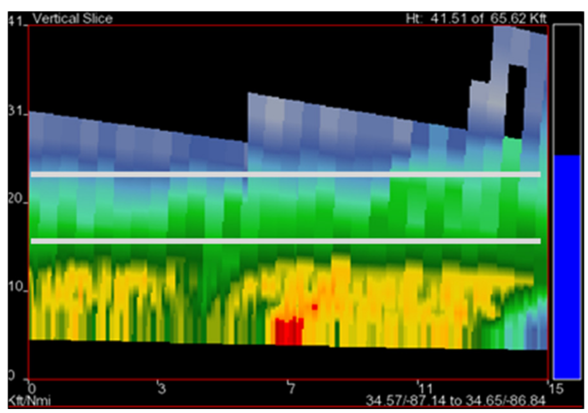

Figure 16: Same as Figure 11, but for 1342 UTC on 6 May 2009.

The convective mode was evolving into discrete cells by 1356 UTC, one minute before the EF-2 tornado touched down that would eventually affect Madison, Alabama as seen in

Figures 17 and 18. Our storm in question on the AWIPS display appeared to have more in common with a mini-supercell, although the source density values remained very low. Conversely, the reflectivity cross section observed a robust updraft had begun to develop with dBZs in the mid to upper 50s well into the mixed phase region. There is now a strong charging mechanism, but it was not in place soon enough to generate significant total lightning before the tornado formed. By 1402 UTC (not shown) the storm had maintained a robust updraft and the total lightning jumped to 185 sources since the 30 sources were observed in Figure 17.

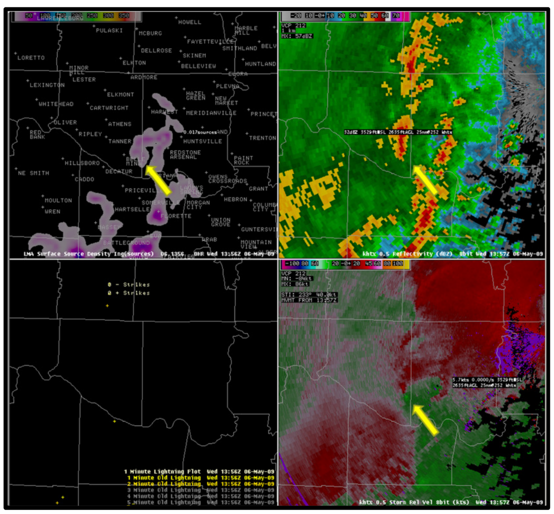

Figure 17: Same as Figure 10, but at 1356 UTC on 6 May 2009.

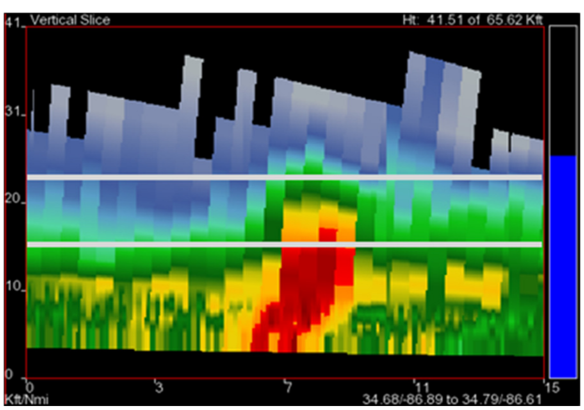

Figure 18: Same as Figure 11, but at 1356 UTC on 6 May 2009

4. Comparison of Events

Table 1 contains a basic comparison of the pre-storm conditions for all four of the events discussed. The comparison looks at each event's CAPE, helicity, height of the -10℃ and -20℃ isotherms as well as the mode of convection. Subjectively, there appeared to be little distinction in the events for the convective mode, particularly since 6 May and 21 January both resulted in mini-supercells, but the 21 January example never produced significant total lightning values. The height of the isotherms roughly defining the region of mixed phase did not appear to be significant in and of themselves. What was more significant was whether or not the updraft ever reached/exceeded the -10℃ isotherm and with what intensity. For 10 December and 21 January, the updrafts were sufficiently shallow to prevent enough charging to occur to generate enough total lightning for a lightning jump to be observed. The 6 May EF-0 tornado near Decatur, Alabama was an extreme example of this as the storm updraft had almost completely dissipated as the convective mode shifted from a line of cells to a mini-supercell.

What did appear to separate the lightning jump cases from the non-lightning jump cases was the CAPE and helicity. The classic lightning jump event from 2 March 2012 had strong CAPE and high shear. Figures 1 and 2 demonstrated that once the updraft vigorously extended into the mixed phased region, as shown in the respective radar reflectivities, the total lightning values rapidly increased. In Figure 2, the radar reflectivity lagged the total lightning display due to the slower update time of radar volume scans compared to total lightning observations. However, the physical link demonstrated gives forecasters the confidence to use a lightning jump as a precursor to a severe weather event. Compared to 2 March 2012, the examples from 10 December 2008 and 21 January 2010 demonstrate a clear low CAPE but high shear environment. These examples lacked the thermodynamic support to develop intense updrafts extending well into the mixed phase region. Tornado genesis was driven by the strongly sheared environment, which was unfavorable for lightning production. The result was two EF-2 tornadoes that had no significant total lightning observations.

The true outlier was the 6 May 2009 example. This occurred well into the warm season, all three tornadoes observed had limited total lightning observations. As a result, the time of year is not the best identifier for determining whether or not a lightning jump could occur.

With that said, the high shear and low CAPE storms are typically associated with cold season

	10 Dec 08	06 May 09	21 Jan 10	02 Mar 12
CAPE ($J\ kg^{-1}$)	115	700	100	1000
Helicity (m^2/s^2)	450	287	231	350
-10℃ m (kft)	5200 (17.1)	5090 (16.7)	4500 (14.9)	4575 (15)
-20℃ m (kft)	6700 (21.9)	7000 (23)	6100 (20)	6100 (20)
Type	QLCS	Line, Mini-supercell	Mini-supercell	Supercell

Table 1: A listing of all four events discussed in this presentation, with 2 March 2012 being the "traditional" lightning jump event. Each event has its associated observations of CAPE (J/kg), helicity (m^2/s^2), -10℃ isotherm height in meters (kilofeet), and the type of convective event.

events, which had led the authors to originally consider these null events a feature of cold season storms only. Obviously, the 6 May example proves otherwise. The 6 May example appeared to be a hybrid event as it did have the available CAPE to generate a strong updraft in the mixed phase region after the third tornado that resulted in a lightning jump (Figure 11). Still, the initial storms did not have significant lightning preceding severe weather. Like the 10 December and 21 January cases, the 6 May examples had updrafts that did not have large reflectivities observed in the mixed phase region.

Overall, there is a strong case to make that a low CAPE and high shear environment has a much greater chance of producing severe weather without a corresponding lightning jump. This was discussed to some degree in Schultz et al. (2009; 2011). The underlying principle fits our physical, conceptual model of charging for lightning being driven by the strength of the updraft (observed with radar reflectivity) in the mixed phase region. Storms that do not have a strong updraft in the mixed phase region lack the ability to generate enough charging to create the amount of lightning activity that would generate a lightning jump. Predominantly for the northern Alabama region, these low CAPE and high shear environments occur during the cold season. However, as the 6 May 2009 example showed, storms that do not reach the mixed phase region but with sufficient shear can still produce severe weather without a lightning jump.

5. Conclusions

The purpose of this presentation was not to dismiss the utility of total lightning. In fact, the effort was to further promote greater use by providing additional insight to our operational partners on the physical characteristics of what drives a lightning jump. For this presentation only three examples were demonstrated where there was no lightning jump associated with a severe weather event. This is an extremely small sample size compared to all of the operational cases where a lightning jump aided a forecaster in the warning decision support process. Ultimately, these examples from both the traditional case (2 March 2012) and the null events (10 December 2008, 6 May 2009, and 21 January 2010) demonstrate what we expect with total lightning. Total lightning requires sufficient charging to occur and this charging requires a vigorous updraft in the mixed phase region. Without this, not enough charging occurs and severe weather is observed without a lightning jump.

It is necessary to continue to investigate the use of total lightning operationally in more depth as end users are beginning to have access to and rely on total lightning more. This is due to several factors. These factors include more ground based lightning mapping arrays coming online across the United States, the availability of lightning observations from Earth Networks, and the launch of the Geostationary Lightning Mapper aboard GOES-R. With this greater availability and with forecaster including total lightning observations in their procedures, it is vital to provide training to demonstrate that total lightning is not a one size fits all solution. The vast majority of cases do demonstrate that a lightning jump will precede most severe weather events. However, as demonstrated in this presentation there are specific times, such as low CAPE and high shear environments, where a vigorous updraft will not extend into the mixed phase region.

By educating operational end users in these situations, such as SPoRT is doing with its own upcoming modules, forecasters are more knowledgeable about total lightning and how it applies to their physical, conceptual model of a thunderstorm. While most low CAPE and high shear events are in the cold season, there are cases, such as 6 May 2009, where a storm's updraft will not reach the mixed phase region. Therefore, a low CAPE and high shear environment is a strong indicator that total lightning will likely not be a useful tool in severe weather operations. Still, it is beneficial to make sure storms are reaching the mixed phase region. With this deeper understanding of total lightning and the physical processes that lead to a lightning jump, the result is a more robust product. Now, operational end users will understand situations where total lightning is less effective and will not dismiss this new and exciting data set out of hand when it "fails".

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