Lightning Signature Assessment to Forecast Tornado Formation

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Abstract**—**Recent research suggests that a maximum rate of lightning strikes occurs at least 15 to 20 minutes prior to tornado formation within a supercell storm. These maxima are associated with strengthening updrafts as they appear in radar measurements. An increase in lightning rates correlates with an increase of shear in the lower part of the storm. In combination with a strong updraft or downdraft, this shear can provide the ingredients for rotation and possibly a tornado. Polarity reversal of lightning around the time of tornado touchdown also has been examined. Thus, increasing lightning flash rates and reversal of lightning strike polarity are potential indicators of possible tornado formation. This research examines these findings by conducting a GIS analysis of tornado and lightning data from a severe storm event on 9 May 2006, which occurred near the rural town of Anna, Texas. This storm produced several tornadoes ranging from F0 to F3. The lightning data show three distinct patterns in the 50 minutes prior to the first reported tornado touchdown, which include an increase in lightning strikes, an increase in the percent of positive polarity strikes, and a spatial concentration of strikes prior to touchdown along the path of the tornado. As the study of lightning signatures becomes more refined, forecasters can use real time lightning data to compliment radar signatures in an effort to predict tornado development in severe storms.

Keywords**—**forecasting, GIS, lightning, severe storms, tornadoes

I. Introduction

LIGHNTING strikes the earth about 100 times every second, and it is deadlier than any other natural phenomenon [1]. Recently, scientists studying lightning have graduated from looking at the basics of lightning characteristics to applying what is known about lightning, especially lightning polarity, to predict the environment of a storm and also to forecast the formation of tornadoes in severe storms. This paper examines the role lightning plays as an innovative tool in the field of meteorology demonstrating that the development of lightning patterns in a storm can signal the formation of a tornado.

Making severe weather forecasts and warning the public in time is vital. However, meteorologists today do not have enough tools or techniques to forecast tornadoes in advance and 75 percent of the time, a tornado forecast is a false alarm. Projects such as this, aimed at assessing the connection between lightning and tornadoes, will help meteorologists examine lightning patterns in real time providing a tool to more accurately forecast and detect the location of possible tornadoes. As a result, the public will be safer in tornado-prone areas, and meteorologists will have a better understanding of lightning formation and lightning patterns associated with tornado development.

II. Lightning Formation

Recent research has yielded new theories concerning the way lightning is formed. The University of Florida Research Group has been studying x-ray emissions from lightning and concludes that these emissions are linked with the formation of lightning through a process known as runaway breakdown [2]. In this process, still unconfirmed since it was first suggested in 1961, subatomic particles, such as the electrons found in lightning, acquire a quality that reduces the drag on them as they accelerate. The faster they travel, the less drag they experience in a situation analogous to a runaway train going down a steep grade. As the high-energy electrons collide with air molecules within the cloud, they create more electrons from the collisions. When the cloud builds enough negative charge to overcome the insulating capacity of the air, lightning is discharged.

A study of Florida thunderstorms by American and Japanese researchers reveals that rising pockets, or bubbles, of lightning are associated with a rising, positively charged layer in thunderstorms [3]. The rising concentrations of lightning are typically 3 to 6 kilometers in diameter and about 1 to 3 kilometers in height. These concentrations begin at the freezing level in the cloud with 58 percent of the pockets rising at the rate of 11 to 17 meters per second. The researchers suggest that the lightning pockets are comprised of negative leaders that tend to propagate through the positively charged bubbles.

Recently, studies have been performed to isolate factors that affect the characteristics of lightning, such as flash rate, current, and multiplicity. Scientists from universities in Tel Aviv, Israel, analyzed lightning data from winter storms that traveled over the Mediterranean Ocean and into the northern and central parts of Israel [4]. When the storms were over land, there was a maximum of ground strikes over Mount

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Carmel. The researchers conclude it is due to topographical forcing. Also, lightning in their study was detected at a higher frequency over the sea during the mid-winter months. However, the frequency in the summer storms was the same over land or sea. The research indicates the heat and humidity fluxes from the warmer sea destabilized the colder air above, fueling convection, and in turn, creating more lightning. Additionally, topography and enhanced convection affected the location of lightning strikes.

III. Lightning Charges

While most lightning delivers a negative charge to the ground, scientists have observed that about five percent of lightning strikes deliver a positive charge. That is, the stepped leader is positively charged and contacts a negative charge near the ground to create lightning. Positive lightning occurs when the positive, upper region of a cloud is blown to the side by strong winds coming within close proximity of a mountain or the surface of Earth.

The Severe Thunderstorm Electrification and Precipitation Study (STEPS 2000) put forth a theory about how positive lightning might occur. Researchers documented numerous positive lightning strikes and measured the charge structures of thunderstorms for eight weeks [5]. The preliminary data indicate that the charge structure in thunderstorms often is inverted with the negative charge on top and the positive charge below. These data were confirmed by weather balloons from the National Severe Storms Laboratory. The STEP 2000 members suspect there may be a link between reversal of charge structure in a storm and positive lightning. However, it is still not understood how a storm cloud reverses its electrical charge.

Other researchers indicate that charge structures are more complex than previously thought when mesoscale convective systems were analyzed. A mesoscale convective system (MCS) is an organized cluster of thunderstorms in which the whole system exists longer than an individual embedded thunderstorm, and it is generally larger than a supercell thunderstorm. Hunter et al. [6] measured 11 distinct charge layers in a MCS with 10 of the 11 layers concentrated in an area five kilometers deep and coinciding with the inflow region of the MCS, which had a charge structure comprised of multiple layers of opposing charges.

The International H2O Project [7] studied the link between positive lightning and severe weather, such as storms producing hail and tornadoes. The researchers found that storms with predominantly positive lightning have stronger updrafts that create a deep column of liquid water in the storm. This mix of supercooled water and ice crystals electrify a storm, and the researchers believe it is the stronger updrafts that change the charge structure and produce positive lightning. In the H2O project, strong updrafts in the severe storms ingested additional moist air that modified the cloud composition enough to create positive lightning.

Lang and Rutledge [8] observed a total of 11 thunderstorms and concluded that those producing positive lightning had significantly large volumes of updrafts reported to be greater than 10 meters per second and produced more rain and hail than other storms. It appears the positive lightning results from an elevated region of positive charge, combined with enhanced net positive charge regions from the large updrafts. Both the International H2O Project and this study suggest strong updrafts are a key ingredient for positive lightning.

IV. Tornado Prediction

As lightning polarity and its relationship with severe weather are examined, the importance of the patterns becomes more evident. If researchers could look deeper into how lightning behaves just before hail or a tornado forms, they could save property and lives. Tornadoes usually form where a cold downdraft at the rear of a storm meets a warm horizontal inflow from an updraft near the base of the storm. This downdraft is accompanied by surrounding winds spinning clockwise and is usually situated near a counterclockwise spinning mesocyclone within the larger supercell storm. The downdraft merges into the outside of the updraft forming a hook-shaped region of rain. The hook shape on radar alerts meteorologists to the possible formation of a tornado.

Gatlin & Goodman [9] analyzed lightning rates in two tornadic supercells in the southeastern United States. In particular, they noted that a relative maximum of lightning rates occurred at least 15 to 20 minutes prior to tornado formation within the storm. Some of these maxima were associated with strengthening updrafts as they were measured on radar. In the first supercell storm they studied, the increased rate of lightning strikes correlated with the increase in shear in the lower part of the storm. Wind shear in combination with an updraft or downdraft can provide the ingredients for rotation, and possibly a tornado. The study suggests increasing lightning flash rates might provide a warning of possible tornado formation. Polarity reversal of lightning around the time of tornado touchdown also has been studied. Knapp [10] found that lightning in many storms switches polarity about ten minutes before a tornado formed. An analysis by MacGorman and Burgess [11] found the most damaging of tornadoes in a storm formed after positive lightning peaked and began to decrease, leaving negative flashes dominant. The findings by Seimon [12] were similar when he studied the F5 tornado that touched down in Plainfield, Illinois, in 1990. With so many instances of polarity change occurring around the time of tornado touchdown, it seems plausible that lightning signature can help predict tornado formation.

Researchers in the southeastern United States studied tornadoes that formed from tropical storm Beryl in 1994 and their association with cloud-to-ground lightning. Contrary to lightning patterns found in supercell thunderstorms in the Midwest, lightning patterns in tropical storms spawning tornadoes exhibit a decrease in cloud-to-ground lightning rates

30 minutes before tornado touchdown. Some of the cloud-to-ground lightning stopped forming immediately as a tornado touched down. Also, no shift in lightning polarity occurred around the time of tornado development. Overall, lightning flash rates were higher in cells that formed tropical cyclone tornadoes. However, positive lightning was more common in tropical storm Beryl's non-tornadic cells, and median peak currents were higher [13].

In summary, research of tornadoes in certain regions indicates that maximum lightning rates occur at least 15 to 20 minutes prior to tornado formation within a supercell storm. These maxima of lightning rates are associated with strengthening updrafts. An increase in lightning rates correlates with an increase in shear in the lower part of the storm, which in combination with an updraft or downdraft can provide the ingredients for rotation and possibly a tornado. Polarity reversal of lightning around the time of tornado touchdown also has been examined. Some studies indicate that there is a polarity reversal preceding the formation of a tornado in a supercell storm. Thus, increasing lightning flash rates and reversal of lightning strike polarity are potential indicators of possible tornado formation.

V. PROCEDURE

The research questions address whether relationships exist between tornado formation, an increase in lightning activity, and a reversal in lightning polarity. The primary focus of this study was to analyze cloud-to-ground (CG) lightning data from the 9 May 2006 severe storm event in Collin and Grayson Counties near the town of Anna, Texas, which lies within the region of the U.S. referred to as tornado alley. Relative to other states, Texas is ranked number 1 in tornado frequency, injuries, deaths, and damages.

This storm system produced several tornadoes ranging from F0 to F3 in intensity. The first tornado, an F0, was spotted at 10:19 pm three miles west of Anna. By 10:29 pm, an F1 tornado was spotted just north of Anna, and tornadoes continued to be reported through 10:51 pm. Fig. 1 is a 500-millibar chart of the synoptic conditions associated with this storm, which reveals a deep upper-level trough over southwest North America.

The lightning data associated with the Anna, Texas, tornado activity was taken from the United States National Lightning Detection Network (NLDN). The NLDN has been measuring the time and location of lightning events across the continental United States since 1989 using more than 100 sensors to provide real time and historical data to the National Weather Service, the electric utility industry, other commercial users, and university researchers.

Archived lightning data from the 9 May 2006 outbreak in northeastern Texas were obtained from the NLDN and incorporated into a GIS. The GIS plotted the locations of the CG lightning strikes within the vicinity of the Anna storm. The lightning strikes are displayed in ten-minute intervals starting at 9:40 pm, which is 50 minutes prior to the spotting of the F1 tornado. The data analysis ends at 10:48 pm as the storm moved into neighboring Grayson County.

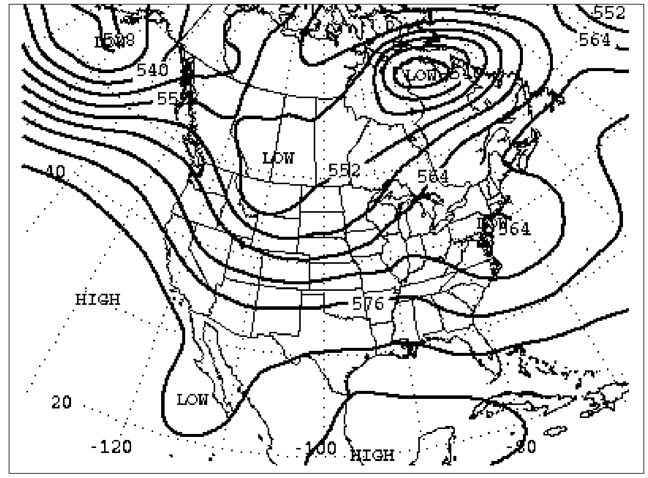

Fig. 1 May 9, 2006 500-millibar synopsis

VI. RESULTS

The late-night tornadoes that swept through rural North Texas on 9 May 2006 killed three people, hospitalized ten residents, and reduced homes to bare concrete slabs. Although tornado sirens were heard in Anna, there were no audio warnings for the residents of Westminster, which underscores the significance of analyzing the results of research examining the association between lightning and tornadoes, which could provide citizens with adequate lead-time to seek shelter before such extreme events.

A. Tornado Timeline

The following timeline describes the tornado outbreak that began with the National Weather Service (NWS) issuing a Severe Weather Statement for north Collin and south east Grayson Counties at 9:30 pm Central Daylight Time (CDT) on 9 May 2006.

9:30 pm - NWS meteorologists detect severe thunderstorms capable of producing golf ball size hail and destructive winds in excess of 70 mph. The storms were moving east at 15 mph.

9:59 pm - NWS issues a severe thunderstorm warning for north central Collin and south east Grayson Counties until 11 pm after detecting a severe thunderstorm now moving east at 30 mph and capable of producing quarter size hail and destructive winds in excess of 70 mph.

10:08 pm - NWS issues a tornado warning for north central Collin County until 11:00 pm after detecting a developing tornado on radar moving east at 20 mph.

10:19 pm - NWS issues a severe weather statement for Collin County in the form of a tornado warning when trained weather spotters report a tornado located three miles east of Anna.

10:29 pm - trained weather spotters report a tornado just north of Anna moving east at 20 mph.

10:34 pm - the tornado warning continues for north central Collin County as trained weather spotters report a tornado four miles northeast of Anna moving east at 15 mph.

10:39 pm - spotters report a large tornado five miles northeast of Anna moving east at 10 mph producing debris.

10:51 pm - the tornado warning continues for Collin County as spotters report the tornado five miles east of Westminster moving northeast at 20 mph. The NWS issues a tornado warning for southeastern Grayson County until 11:15 pm stating that in addition to tornadoes, large hail and damaging winds are likely with this storm.

B. Data Analysis

To facilitate the examination of possible relationships between the cloud-to-ground lightning strikes and the tornado event, the NLDN data were divided into ten-minute intervals (table I). The F1 tornado was spotted at 10:29 pm CDT. During the ten-minute interval from 9:40 to 9:49, which occurred 40-50 minutes prior to tornado formation, there were 36 CG strikes taking place at mean rate of 3.6 strikes per minute. Each of these strikes were negatively charged with peak currents ranging from -4.2 kA to -13.9 kA. Between 9:50 to 9:59, 30-40 minutes before the tornado, there were 27 negative CG strikes at a rate of 2.7 per minute with currents from -3.9 kA to -12.7 kA.

The strike rate increased significantly 20 to 30 minutes prior to the tornado being spotted. From 10:00 to 10:09, there was a total of 56 CG strikes at a rate of 5.6 per minute, and for the first time, three strikes were positive. While the negatively charged CG lightning carried peak currents ranging from -3.9 kA to -13.4 kA, the positively charged strikes had peak currents ranging from 32.7 kA to 67.1 kA.

The strike rate continued to increase 10 to 20 minutes before tornado touchdown with a total of 76 strikes occurring between 10:10 and 10:19 at a rate of 7.6 strikes per minute. The number of positive strikes during this ten-minute interval doubled to six with peak currents ranging from 23.2 kA to 67.7 kA. The peak of CG lightning intensity was exhibited during the final ten minutes before the F1 tornado struck at 10:29 pm CDT. From 10:20 to 10:29 there was a total of 80 strikes occurring at a rate 8.0 per minute. The number of positive strikes nearly doubled again during this interval to 11 and carried peak currents ranging from 18.2 kA to 152.2 kA, which was the highest electrical discharge of the storm. Fig. 2 depicts the total lightning strikes from 10:00 to 10:29 as tornado traveled northeast of Anna.

TABLE I
CLOUD-TO-GROUND (CG) LIGHTNING

Time (PM CDT)	Negative Strikes	Positive Strikes	Total Strikes
9:40-9:49	36	0	36
9:50-9:59	27	0	27
10:00-10:09	53	3	56
10:10-10:19	70	6	76
10:20-10:29	69	11	80
10:30-10:39	69	1	70
10:40-10:49	47	3	50

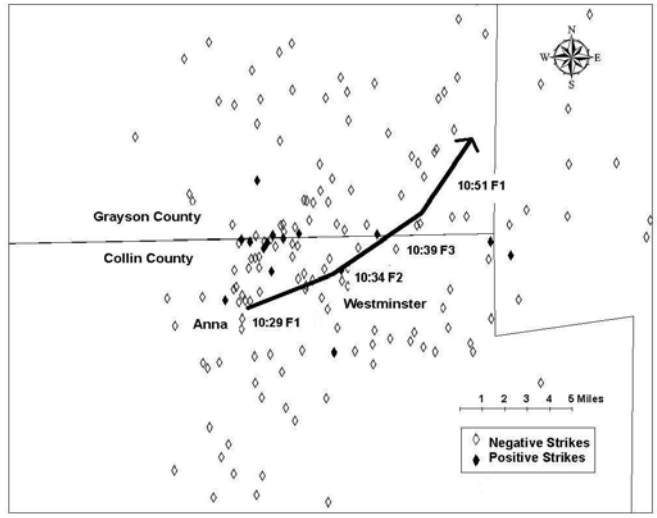

Fig. 2 Tornado track and CG strikes 10:00-10:29 pm CDT

Once the F1 tornado was on the ground, the lightning activity began to decrease. From 10:30 to 10:39 there was a total of 70 strikes, and only one of these was positive. During the final ten-minute interval of the data analysis from 10:40 to 10:49, the number of lightning strikes decreased to 50 with three positive strikes.

C. Findings

There appear to be three distinct patterns observed in the association between CG lightning data and the tornado. During the 30 minutes prior to the tornado touchdown, the number of CG lightning strikes increased and began to decrease as the tornado was touching down. Also, the percentage of positive CG lightning increased until the tornado was spotted, and then decreased rapidly as the tornado was on the ground. From about 40 to 50 minutes before the tornado formed, the lightning was negative strike dominated with no positive strikes recorded. Thirty-minutes before touchdown, the positive strike rate began to increase. The positive strike rates compared with all strikes from 20 to 30 minutes prior to touchdown was 5.4 percent, from 10 to 20 minutes prior it increased to 7.9 percent, and from 0 to 10 minutes prior it increased to 13.6 percent. After the tornado formed, there was a significant decrease in the percentage of positive strikes. During the first ten minutes of the tornado being on the ground, the positive strikes comprised just 1.5 percent of all strikes.

Finally, the spatial pattern of the CG lightning changed in the 30 minutes prior to the first tornado. The CG lightning strikes are concentrated near the start of the tornado path about 20 to 30 minutes before the tornado was reported. The strikes continue to be centered around and ahead of the tornado path. Similarly, the positive strikes are concentrated near the path of the tornado.

VII. CONCLUSIONS

The CG lightning patterns in the Anna, Texas, storm are similar to patterns in other documented storms. Several studies have recorded changes in lightning polarity and the increase in strikes during the 10 to 20 minutes prior to the tornado touching down. While there was not a complete shift in polarity in the Anna storm, there was a marked increase in positive polarity strikes within minutes of tornado formation.

Meteorologists can locate hook echoes and areas of rotation on Doppler radar to indicate a possible tornado. With more research focusing on the connection between lightning and tornadoes, meteorologists one day will be able to consider lightning patterns as a tool to forecast and pinpoint the location of possible tornadoes. As the study of lightning signatures becomes more refined, forecasters can use lightning data to compliment radar images when seeking developing tornadoes.

The most significant aspect of this research is the impact it could have on the public. When forecast meteorologists can better predict the timing and location of tornado touchdown, they can better warn the public to save lives and property. People might heed the warnings issued by their local weather forecaster because the false alarm rate for tornadoes should be reduced. In short, the public will be safer in tornado-prone areas, and meteorologists will have a better understanding of the association between lightning and tornadoes.

Recent lightning research has written a new chapter in our knowledge of lightning. Atmospheric scientists have discovered a new tool they can use to help better understand the structure of a storm, and help predict the dangers of severe weather. The new tool is lightning, and with further research to help refine our understanding of the role it plays in severe storms and tornado formation, forecasters will one day include lightning data in the list of factors to consider as a storm develops.

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