9.4 SIGNIFICANT TORNADO EVENTS ASSOCIATED WITH CELL MERGERS

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1. INTRODUCTION

Cell mergers have long been believed to play a role in tornado production, although the exact mechanisms are poorly understood. Several studies have noted the resultant thunderstorm intensification that occurs during a cell merger event (e.g., Cunning et al. 1982, Westcott and Kennedy 1989). Numerical simulations (e.g., Tao and Simpson 1989, Kogan and Shapiro 1996, Bluestein and Weisman 2000) have examined the role cell mergers play in the evolution of a storm, often noting an intensification of the primary storm following a cell merger. Several observational studies (e.g., Lee et al. 2006, Wurman et al. 2007, Rogers and Weiss 2008) have noted the relationship between cell mergers and tornado occurrence. Both Lee et al. (2006) and Rogers and Weiss (2008) found that approximately one-half of tornado reports were associated with cell mergers in separate case studies.

Past studies have developed hypotheses to isolate processes related to cell mergers that may be favorable for tornado production. Rogers and Weiss (2008) noted cell mergers associated with tornado production often occurred within the updraft or rear flank region of the primary storm, while precipitation associated with ancillary cells falling within the inflow of the primary storm may be detrimental to the outcome of the merger. Wurman et al. (2007) observed tornadogenesis occurring nearly coincident with a cell merger in a dual-Doppler radar study, and suggested that the role of storm interaction may be sensitive to the orientation and size of the ancillary storm.

Despite the increasing number of studies documenting the relationship between cell mergers and tornadoes, no known study exists that analyzes a large sample size of cases occurring over a multi-year period. The primary motivation for this study is to establish a five-year climatology of cell mergers associated with significant tornadoes (defined as F/EF2 rating or greater) across the contiguous United States (CONUS).

Anticipating the effect of a cell merger on a supercell thunderstorm in an environment favorable for tornadoes is difficult in an operational setting. It is unclear why certain cell merger events appear to be favorable for tornado production, while others can have a destructive effect on the evolution of the parent storm. Given these difficulties, an attempt is made to record common characteristics of cell merger events associated with all significant tornadoes occurring between 2006 and 2010 across the CONUS. Weaker tornadoes (F/EF 0-1) were not included in this study, primarily to reduce the number of tornado events occurring within marginal environments (Thompson et al. 2003).

2. DATA AND METHODOLOGY

Storm reports were gathered from the Storm Prediction Center (SPC) severe weather database, which includes official *Storm Data* reports collected by the National Weather Service and is produced by the National Climatic Data Center (NCDC). Level II radar data were also collected from NCDC and analyzed using Gibson Ridge software (GR2Analyst). All significant tornadoes (rated F/EF2 or higher) occurring between the years of 2006 and 2010 were included in this study, yielding a total of 718 reports. However, only 669 cases were included in the final analysis, with cases most commonly excluded due to poor radar coverage or uncertainty of the quality of the reported tornado start time and/or location. This study does not include null cases in which mergers occurred but were not associated with significant tornadoes.

Each significant tornado report was carefully examined to determine whether a distinct, ancillary cell merged within +/- 15 minutes (approximately three radar volume scans) of the recorded start time of the tornado. A cell merger is defined as the consolidation of two initially distinct reflectivity maxima of any size exhibiting greater than 35 dbZ on the 0.5° elevation reflectivity image. Included in this definition is not only a separate ancillary cell colliding with a parent cell, but also cell "bridging" resulting from interacting outflows and additional convective development leading to a joining of reflectivity cores (Westcott 1984, 1994). In the case of multiple mergers, the event that occurs closest to the reported tornado start time is used.

A subjective classification of convective mode for each event, similar to that used by Smith et al. (2012), was made in an attempt to differentiate characteristics of varying storm types. For the purpose of this study, the primary goal is to distinguish discrete tornado-producing storms from other storm types, and only includes four convective mode classifications:

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- Discrete: A storm (often a supercell) remaining isolated and distinct from neighboring storms.
- Cluster: A storm embedded within a disorganized group of storms.
- Broken line: A discrete storm embedded within a well-defined but discontinuous (35 dbZ threshold) convective line.
- Line: An identifiable low-level circulation associated with a significant tornado report embedded within a continuous convective line of reflectivity ≥ 35 dbZ with a length ≥ 50 km.

Environmental analysis in this study is derived from an objective analysis scheme that includes surface observations and RUC 40-km gridded environmental data aloft, as described in Schneider and Dean (2008). Similar to the SPC Mesoscale Analyses grids (Bothwell et al. 2002), this information provides three-dimensional estimated environmental information and allows for the retrieval of parameters frequently used in operational forecasting.

3. RESULTS

3.1 Frequency of Merger Occurrence

When considering the entire sample of significant tornadoes, it is found that 183 out of 669 (27.4%) of significant tornado reports are associated with a cell merger. Separating significant tornado events based on convective mode classification reveals substantial differences among class types (Fig. 1). Of note, only 3 out of 111 mergers (2.7%) of significant tornadoes occurring within a line are associated with a cell merger. Given the rareness of significant tornadoes associated with cell mergers within line mode types, results presented in the remainder of the paper will exclude events classified as lines, unless otherwise noted. A similar proportion of significant tornadoes occurring within discrete storms and cells embedded within clusters (32.7% and 33.1%, respectively) were associated with a cell merger, while a slightly lower percentage (27.8%) was found for significant tornadoes occurring within a cell embedded in a broken line of convection.

There appears to be little distinction in the relative frequency of cell mergers when separated by tornado rating for discrete or quasi-discrete mode types (Fig. 2). The rareness of violent tornadoes (F4/EF4+) tornadoes makes it difficult to draw conclusions about the relationship between cell mergers and tornado rating. However, 29 F4/EF4 events are included in this dataset, and exhibited a similar proportion (34.5%) of cell merger events as lower-rated tornadoes.

The seasonal variation in relative frequency of significant tornadoes associated with cell mergers remains relatively constant through the winter and early spring months (Fig. 3). A small decrease in relative frequency of cell mergers occurs in May, which is the peak of significant tornado activity across the CONUS. A higher relative frequency is observed to occur in August and September when the number of significant tornadoes is low. It is not entirely clear why this trend emerges, but it may be related to weaker flow aloft that is generally prevalent across much of the CONUS (Grams et al. 2012), and the tendency for stronger cold pool development to promote differential storm motion from the mean deep-layer flow (Westcott 1984). One notable outlier is December, which is when the monthly maximum relative frequency is observed to occur. However, the sample size is small for this specific month, and on closer inspection, significant tornadoes only occurred on two days in December within the five year period, with the events confined to Texas and Louisiana.

3.2 Merger Tendencies

An estimate of the time of cell merger occurrence relative to the reported beginning time of the tornado was determined. In a majority of cases (71.4%), the cell merger tends to occur coincident or prior to the time of the tornado report (Fig. 4), with far fewer mergers occurring five minutes or later. Although it is difficult to determine the specific processes involved with each merger case from radar data alone, this result may suggest that interaction between the primary and ancillary cell is occurring prior to the radar-denoted merger time.

Trends in rotational velocity were also determined via analysis of the maximum gate-to-gate shear across the low-level mesocyclone on the lowest available elevation storm relative velocity image. Rather than focusing on the absolute magnitudes of the obtained velocity data, which is sensitive to range from the radar (Andra 1997), trends in the change of rotational velocity with time were analyzed instead (Fig. 5). While the mean change in rotational velocity shows an increase both prior to and after the cell merger, the rate of increase slows in the time frame immediately preceding and following (~+/- 5 minutes) the time of cell merger occurrence.

3.3 Environmental Parameters and Geographic Distribution

Discriminating the environments in which cell mergers occur with significant tornadic storms from those that are less favorable may be useful for operational forecasters in accurately anticipating these events with lead time. An inspection of objectively analyzed environmental information reveals small differences in environmental parameters between cell merger and non-merger tornadic events. Significant tornadoes associated with cell mergers tend to occur in slightly more unstable environments characterized by greater MLCAPE values than those without mergers (Fig. 6); however, significant overlap in the distributions limits the applicability of this result from a forecasting perspective. The difference in convective inhibition was even smaller, with significant tornadoes associated with cell mergers tending to occur in environments with slightly weaker MLCIN (Fig. 7). Also consistent with the seasonal trends, mergers associated with significant tornadoes occurred within slightly weaker-sheared environments, on average, although the overall distribution of environments is similar for both merger and non-merger events. Little difference in the Significant Tornado Parameter (Thompson et al. 2003) was observed.

The geographic distribution of significant tornado reports associated with cell mergers is scattered throughout the eastern two-thirds of the CONUS, with most reports occurring during the first half of the year (Fig. 8). A general northward and westward shift of significant tornado activity occurs during the transition from winter to spring, and back towards the southern latitudes during the transition from the summer into the fall and winter.

3.4 Ancillary Cell Characteristics

The classification of merger types reveals that a majority (64.5%) of tornadic cell mergers involved the collision of an ancillary cell with a primary cell. Cell bridging between a distinct ancillary cell and primary cell accounted for the remainder of cell merger cases (35.5%).

Most ancillary cells included in this study were classified as discrete, non-supercell storms, accounting for 64.1% of cases (Fig. 9). A separate category was assigned to discrete storms that initiated along the trailing outflow of the primary cell, and these events were classified as “flanking line” cells, comprising 10.5% of the cases. Previous studies have focused on the effects of a merger with an ancillary cell originating along the flanking line, with results generally showing an intensification of the primary storm following a merger (Dennis et al. 1970, Lemon 1976). Also of note, ancillary cells originating as left-moving supercells only accounted for two (1.1%) cases, while nine (5.0%) ancillary cells were classified as distinct right-moving storms. Cases in which a QLCS merged with a tornado-producing primary cell accounted for four (2.2%) cases.

The orientation and primary storm-relative position of the merger may be of importance to the evolution of the primary storm, as the ancillary cell has the potential to disrupt the inflow environment and in some cases may be detrimental to tornado production (Wurman et al. 2007). The radar-estimated area of the ancillary cell (Fig. 10), using a continuous area of reflectivity ≥ 35 dbZ, indicates that most ancillary cells are relatively small (< 30 km^2), with less areal coverage of hydrometeors to potentially disrupt the inflow environment. The position of mergers at the time of the initial tornado report relative to the radar-identified low-level circulation center of the primary storm, adjusted to a westerly environmental effective shear vector, tends to frequently occur near or to the south of the low-level circulation for cell collision mergers, and to the west of the low-level circulation for cell bridge mergers (Fig. 11). The median position of mergers for discrete primary storms occurred approximately 1 km at an azimuth of 170° from the low-level circulation center, but a large spatial variation is apparent. Most merger positions located more than 10 km from the low-level circulation center were classified as cell bridge merger types, while a majority of cell collision type merger events occurred within 10 km of the low-level circulation center.

4. SUMMARY AND DISCUSSION

A large sample size of cell mergers occurring nearly coincident with significant tornadoes was analyzed to develop a five-year climatological frequency of these events. Although impossible to determine what, if any, extent the cell merger may have played in the tornadogenesis process in each case using available data sources (e.g., WSR-88D radar), an assumption is made that some influence by cell mergers exists given the number of studies documenting the potential significance of cell mergers to the production of a tornado (e.g., Lee et al. 2006).

Approximately 27% of significant tornadoes occurring between 2006 and 2010 were found to occur within three radar volume scans (~ +/- 15 minutes) of a cell merger event. Little disparity exists in the relative frequency between convective mode types, with exception to significant tornadoes occurring within a convective line, which occurred at a much lower rate. Excluding cases in which the tornado was embedded within a convective line, approximately one-third of significant tornadoes were associated with a cell merger. It is unknown whether these results hold true for weaker tornado events (e.g., EF0-1), but further research is underway to include these cases in future analysis. Cell mergers associated with significant tornado events tended to occur at a slightly higher relative frequency during the summer months across the CONUS, when deep-layer winds tend to generally be weaker and instability is typically greater. Examination of objectively analyzed environmental parameters support this finding, exhibiting slight differences in objectively analyzed MLCAPE and effective shear values, though there is significant overlap in the distributions. It is worth noting that cell mergers associated with tornadoes were observed to occur in every month and spanned a wide geographic area.

Future work on cell merger characteristics should include a null data set involving cell merger events occurring within an environment favorable for tornado production, but in which no tornado occurred. Further inferences about favorable cell merger position and orientation relative to the primary storm, in addition to other vital characteristics such as seasonal and environmental tendencies, would also be useful.

Additionally, a more in-depth analysis of mesoscale processes that may affect the outcome of a cell merger event on a case-by-case basis may prove to assist operational forecasters in anticipating tornadic cell merger events.

ACKNOWLEDGEMENTS

Rich Thompson, Bryan Smith, Chris Broyles, and Jeremy Grams (SPC) collected and provided access to archived radar data, significantly reducing the time required to complete this study. Andy Dean (SPC) provided objectively analyzed environmental data. Dr. Chris Weiss (Texas Tech University) and Steve Weiss (SPC) were involved in exchanges of ideas that were valuable to the completion of this study.

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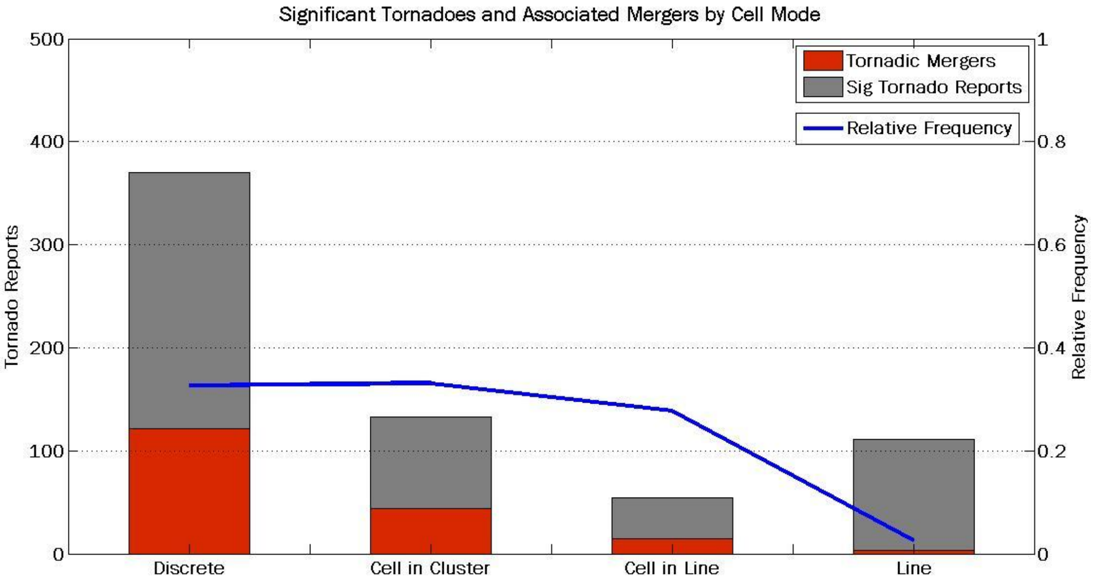

Figure 1. Convective mode classification of all significant tornado reports (grey) compared to those associated with cell mergers (red). The relative frequency of cell merger occurrence for each mode type is represented by the solid blue line.

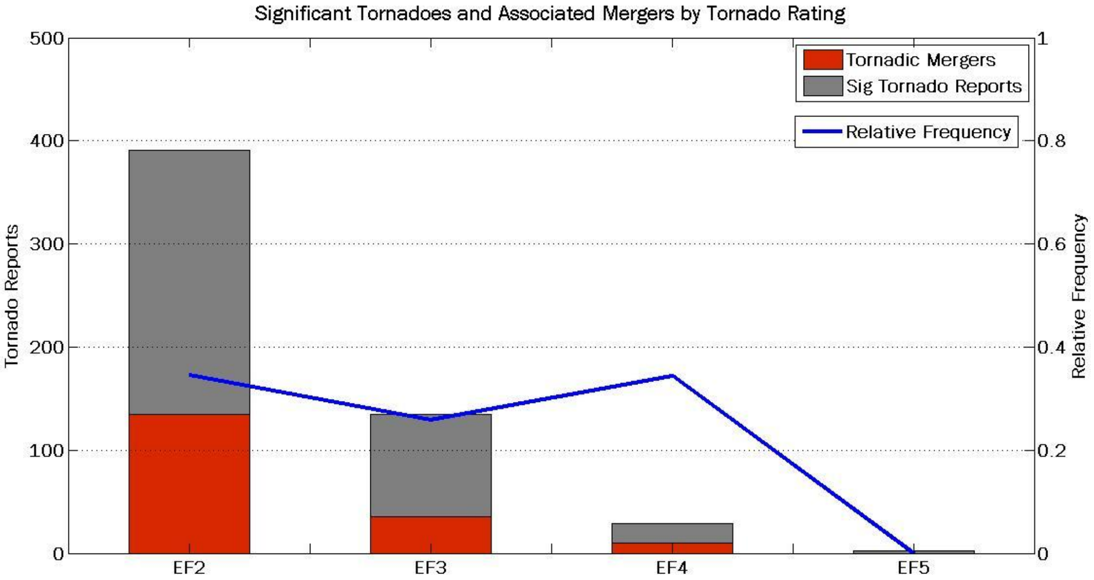

Figure 2. Same as Fig. 2, except for all significant tornadoes (excluding line mode type) separated by rating.

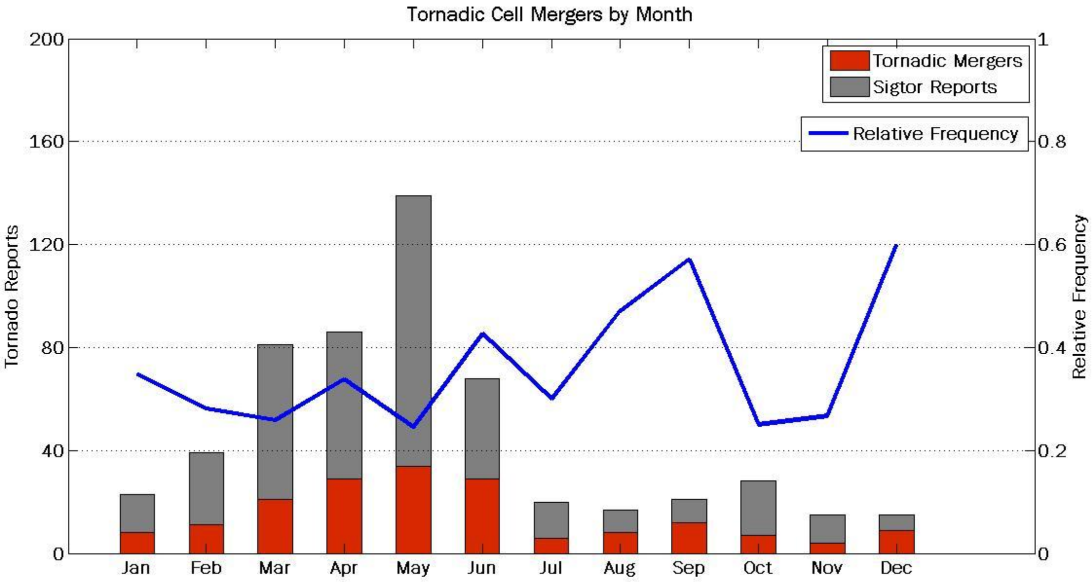

Figure 3. Same as Fig. 1, except for all significant tornadoes (excluding line mode type) separated by month.

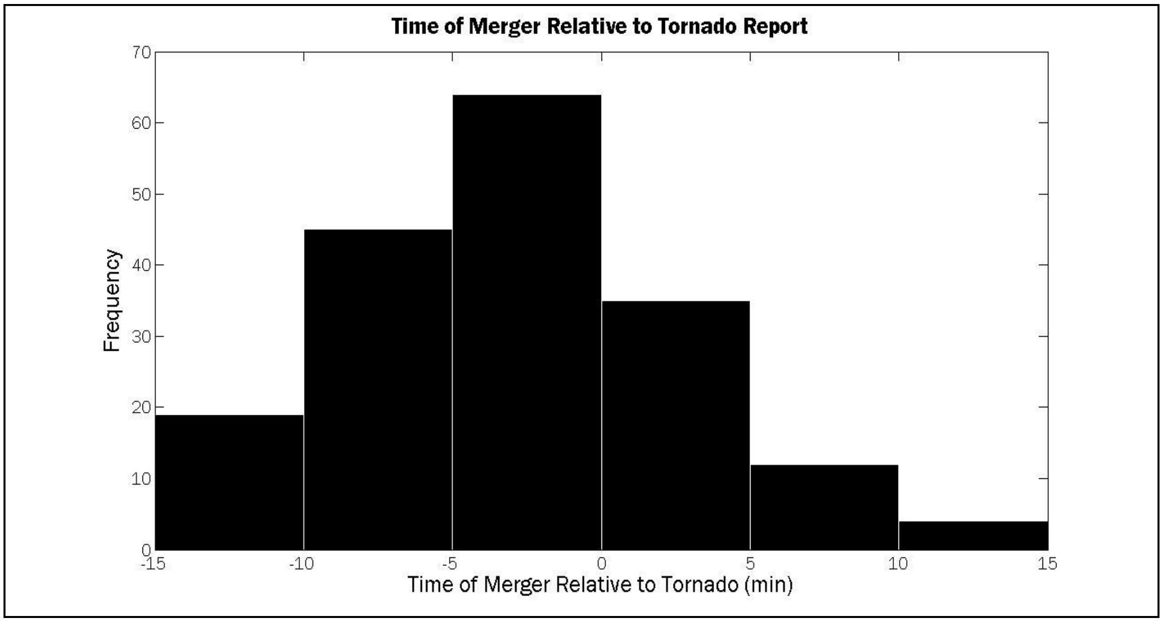

Figure 4. Time of cell merger relative to the initial tornado report time in 5 minute bins.

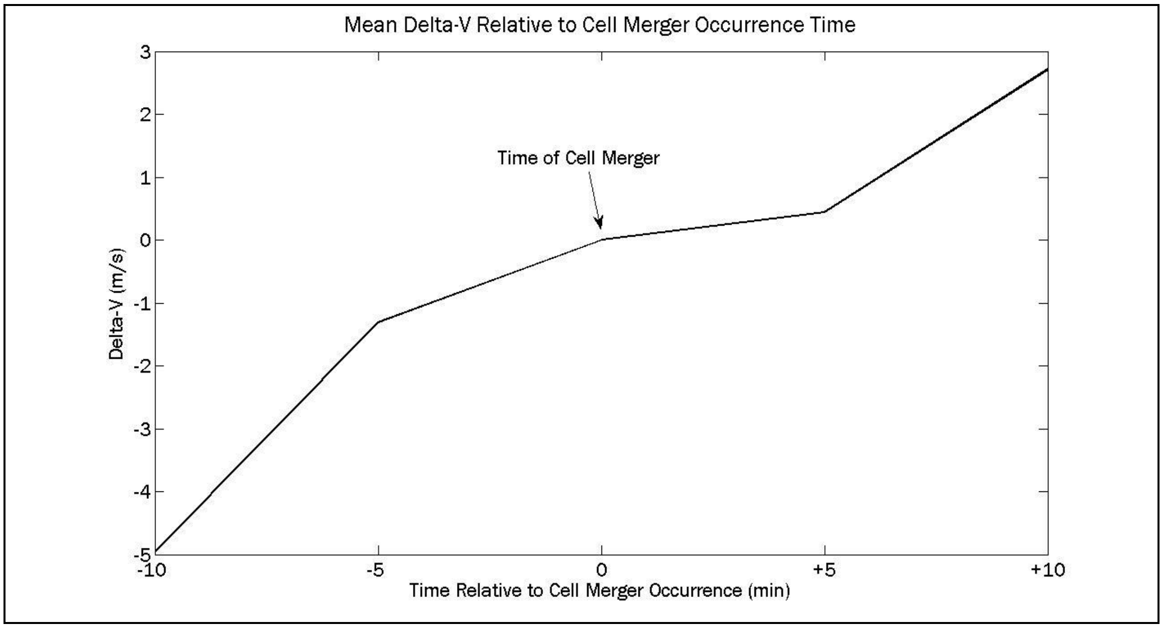

Figure 5. Mean radar-derived maximum delta-v relative to the magnitude of delta-v at the time of cell merger occurrence.

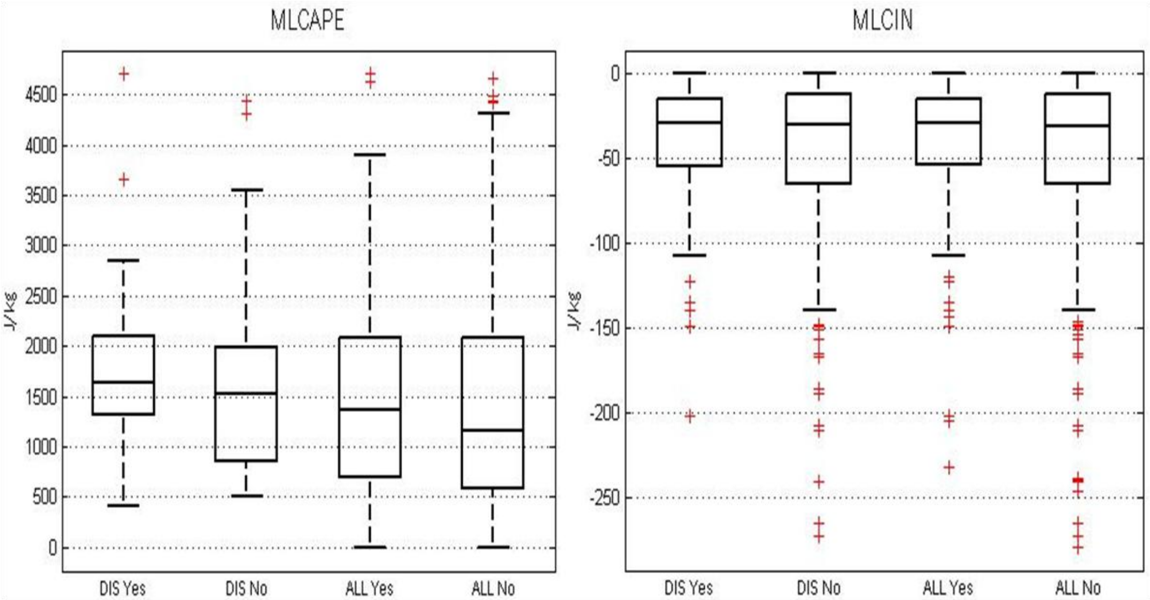

Figure 6. Plot of MLCAPE (left box) and MLCIN (right box) from 40 km gridded RUC-based objective analysis at the time of the initial tornado report. The two boxes on the left side of each plot represent discrete mode type primary storms by whether a merger occurred. The two boxes on the right side represent all modes by whether a cell merger occurred.

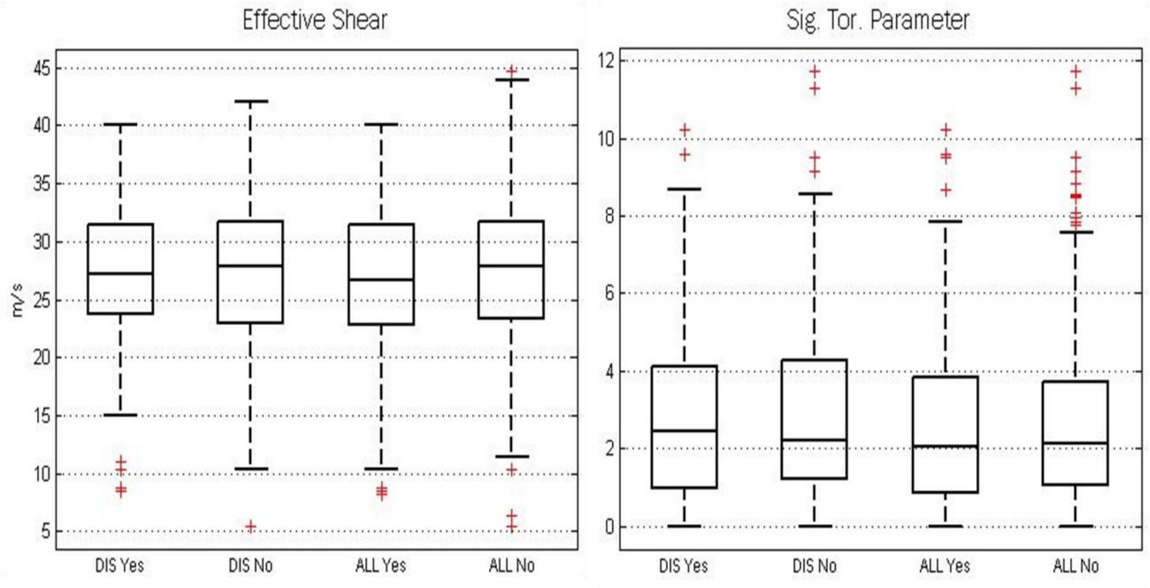

Figure 7. Same as Fig. 5, except for Effective Shear (left box) and Significant Tornado Parameter (right box).

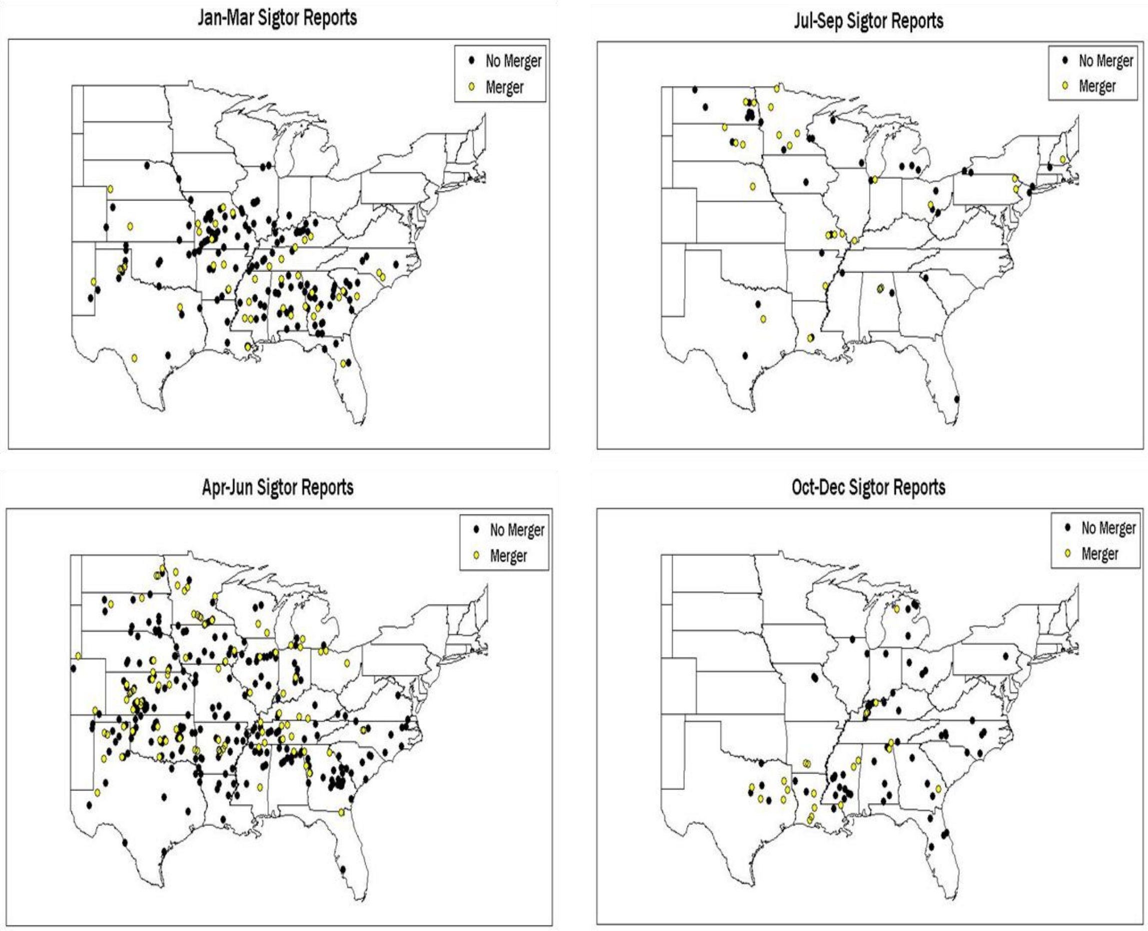

Figure 8. Geographic distribution of all significant tornado reports included in this study divided into three-month periods, with yellow dots representing events associated with a cell merger.

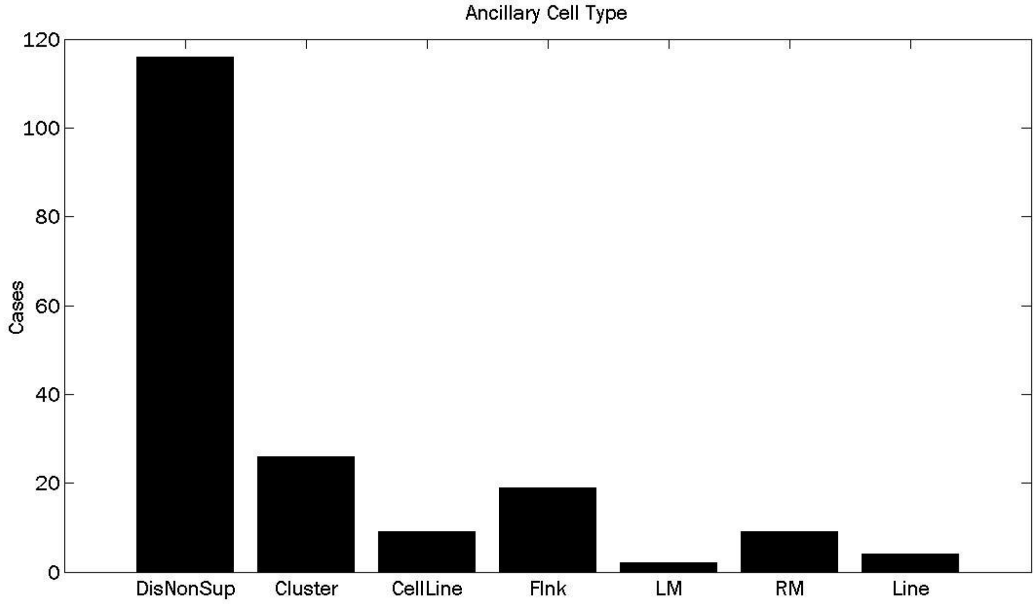

Figure 9. Ancillary cell type for each merger event. The x-axis labels are as follows: "DisNonSup" for discrete non-supercells; "Cluster" for a cell embedded in a cluster; "CellLine" for a cell embedded in a discontinuous line; "Flnk" for an ancillary cell originating along the primary cell flanking line; "LM" for a left-moving supercell; "RM" for a right-moving supercell; "Line" for a continuous convective line.

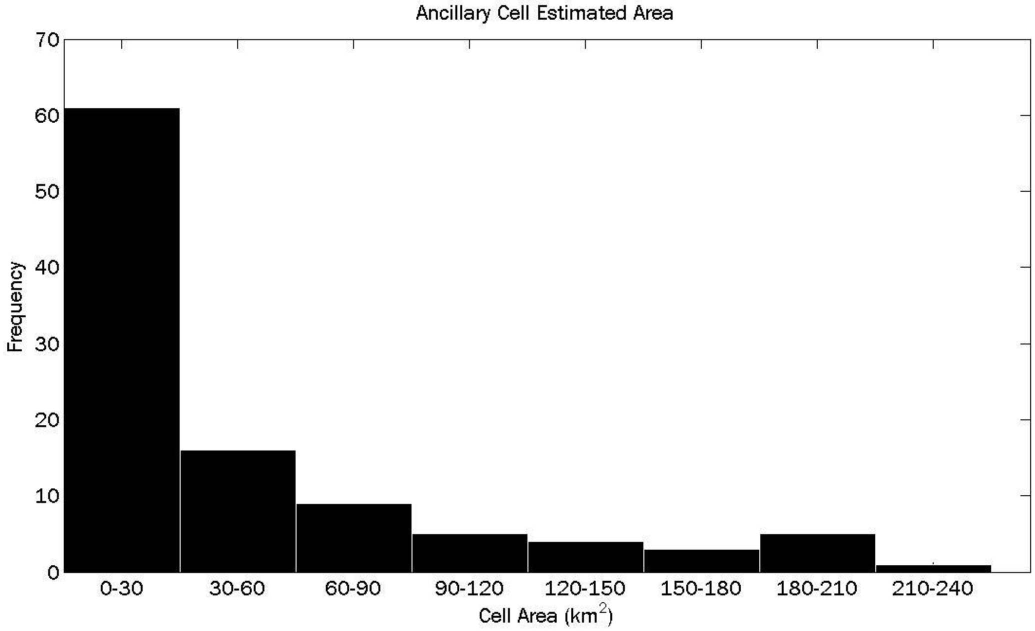

Figure 10. A histogram of the radar-estimated area of the ancillary cell immediately prior to the time of merger.

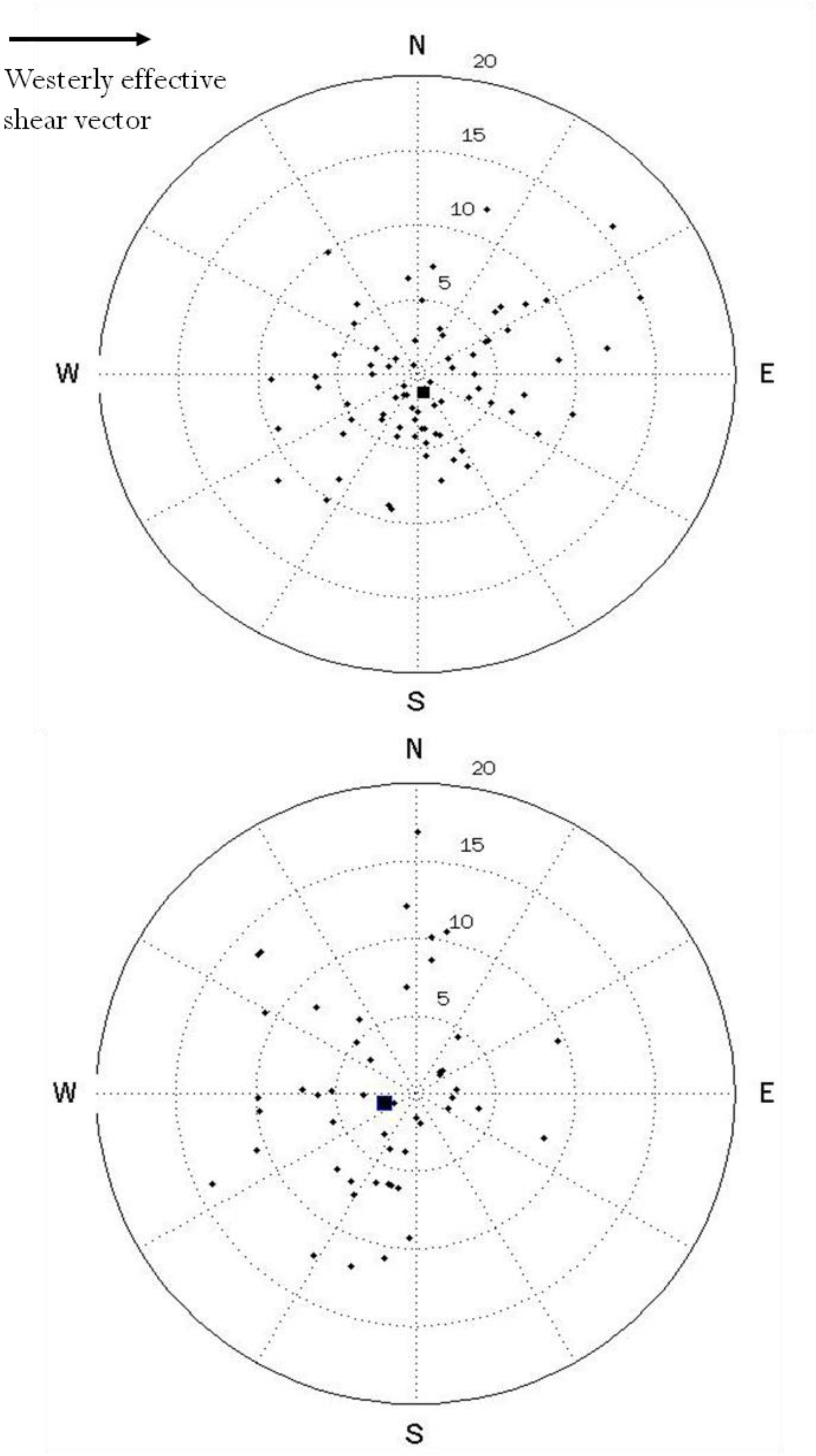

Figure 11. Polar plot of location of the cell merger occurrence for discrete primary storms of cell collision (top) and cell bridge (bottom) merger types, with positions adjusted relative to a westerly effective shear vector. The center of the plot indicates the radar-derived low-level circulation center of the primary storm. The black box is the median merger position. Range ring labels are in km.