P2.18 THE CONVECTIVE MODE AND ENVIRONMENT OF THUNDERSTORMS PRODUCING SIGNIFICANT COOL SEASON TORNADOES IN THE NATIONAL WEATHER SERVICE'S CENTRAL REGION

Fred H. Glass* and Mark F. Britt
NOAA/National Weather Service
St. Charles, Missouri

1. INTRODUCTION

In a previous study examining the years 1950-1999, it was found that nearly half of all tornadoes that occur in eastern Missouri and southwest Illinois during the late autumn and winter are either strong or violent (Britt and Glass 2000). A frequently updated tornado climatology since this initial study continues to support this ratio (see www.crh.noaa.gov/lsx/?n=tor_climatology). Of the many statistics generated, one of the more disturbing findings is that nearly half of all violent tornadoes strike during the winter months in the late evening or early morning hours (10:00 p.m. – 2:00 a.m. LST). In fact, the last violent tornado in the St. Louis Metropolitan Area was an F4 that occurred on February 10, 1959 at 1:40 a.m. resulting in 21 fatalities and 345 injuries.

Curiosity of the storm mode/type generating this deadly winter tornado along with the associated synoptic and environmental conditions has helped fuel further investigation of cool season tornadoes. Britt and Glass (2006 – hereafter BG06) was an initial step, highlighting the synoptic and environmental conditions associated with cool season strong and violent tornadoes in an expanded domain covering the north central United States. They examined the years from 1979-2005 to utilize the North American Regional Reanalysis (NARR) dataset (Mesinger et al. 2006), while defining the cool season as November 16th through the end of February in an attempt to isolate events during the coldest months while also avoiding transitional periods in late autumn and early spring.

This study is the next step in our effort to document the convective mode, storm type/morphology, and environmental characteristics of the severe thunderstorms which produce significant cool season tornadoes (F2/EF2 or greater damage) within the nation's midsection. The cool season is defined as the period from December-February, a time frame commonly referred to as "meteorological winter". Our study domain is the Central Region of the National Weather Service (hereafter NWS CR, see Fig. 1); an area occasionally impacted by severe weather during the coldest months, but where tornadoes are relatively uncommon during the winter. The ultimate goal of this ongoing research is to raise the situational awareness of these cool season events within the operational forecasting community.

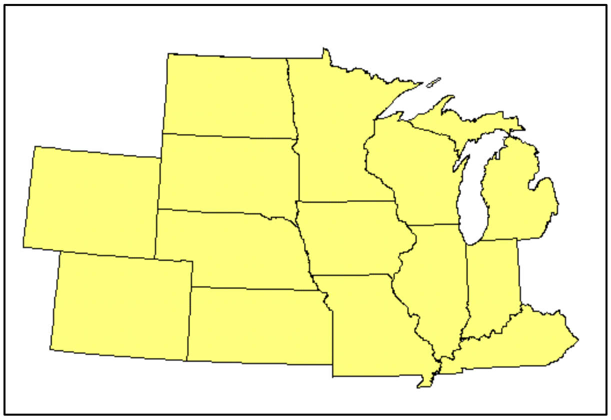

Figure 1. Map of the study domain – the Central Region of the National Weather Service (NWS CR).

2. DATA AND METHODOLOGY

Significant tornado reports from 1997-2009 were obtained from the National Climatic Data Center (NCDC) Storm Events Database. These years were chosen due to the availability of archived WSR-88D data needed to assess the convective mode and storm type of the parent thunderstorm. Thirty-two significant tornadoes were identified on 10 separate days. GR2Analyst (Gibson Ridge, www.grlevelx.com) and the NCDC Radar Data Viewer were then used to analyze volumetric radar reflectivity and velocity data from the WSR-88D site closest to the significant tornado. The convective mode and storm type were determined using radar data from the volume scan nearest the beginning of the tornado. In some cases, radar data from several different WSR-88Ds was examined to help clarify the thunderstorm characteristics.

The parent thunderstorms were classified into one of two possible convective modes: discrete or quasi-**linear** convective system (QLCS). The definitions of these modes closely follow that of Trapp et al. (2005) and Thompson et al. (2008): a discrete cell was a relatively isolated, circular, or elliptical region of reflectivity with maximum values ≥ 50 dBZ; and a QLCS was a quasi-linear region of reflectivity ≥ 40 dBZ, continuously distributed over a horizontal distance of ≥ 100 km, with a major axis at least three times as long as

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*Corresponding author address: Fred H. Glass, NOAA/NWS, 12 Research Park Drive, St. Charles, MO, 63304; email: fred.glass@noaa.gov

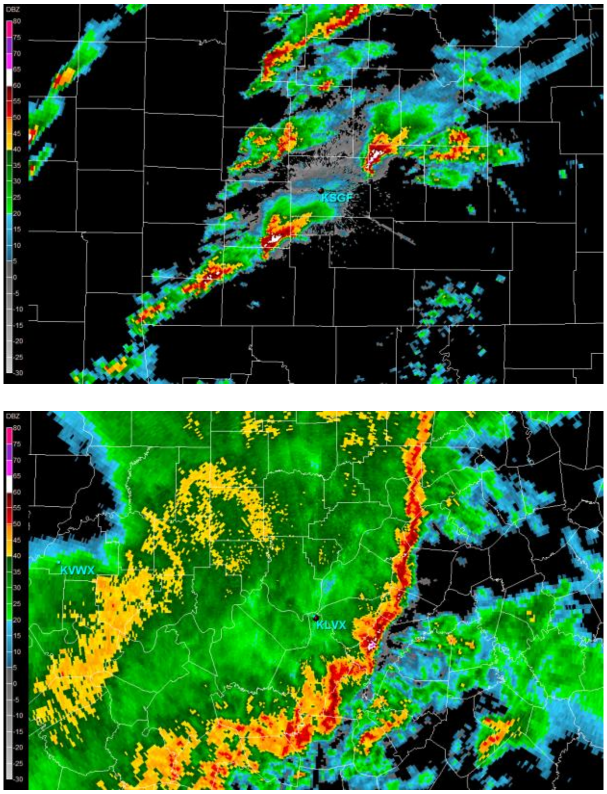

Figure 2. Radar reflectivity images showing examples of the convective modes: discrete cell (top) and QLCS (bottom).

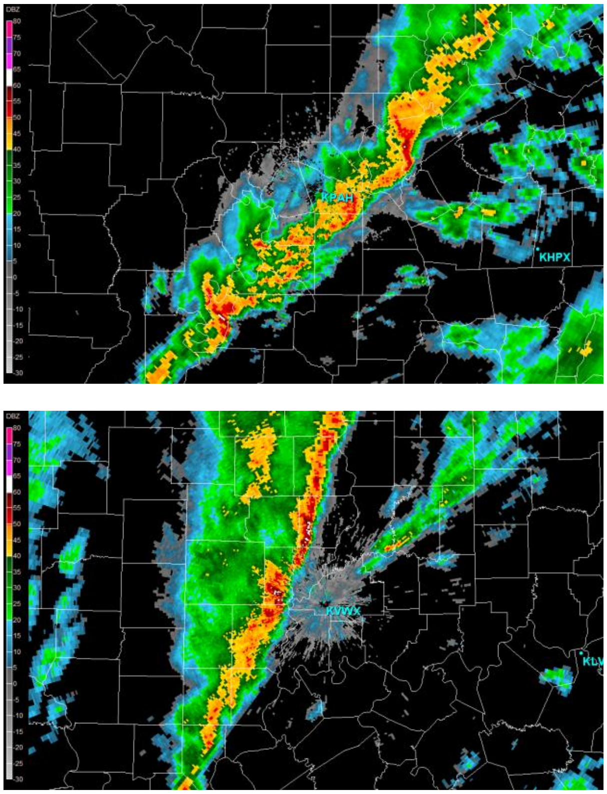

Figure 3. Radar reflectivity images showing examples of the QLCS types: embedded supercell (top) and line mesovortex (bottom).

the minor axis. All of the discrete cells identified were supercell thunderstorms. The QLCSs however were further classified as consisting on an embedded supercell or a line mesovortex (Trapp and Weisman 2003). An example of the convective modes and QLCS types as depicted in radar imagery is shown in Figs. 2 and 3.

Environmental parameters were examined in a manner similar to BG06. The 32 km resolution North American Regional Reanalysis (NARR) dataset (Mesinger et al. 2006) was utilized to obtain pressure, temperature, dew point, and wind velocity at and above 950mb. The NSHARP software (Hart et al. 1999) was then used to extract representative soundings from the NARR dataset from locations in close spatial and temporal proximity (nearest 3 hour) to the tornadoes. In most cases only one sounding was produced per day. An exception was when there was a separation of more than six hours between individual tornadoes, or there was a large distance between tornado locations. This occurred twice leading to a total of 12 soundings for analysis. The nearest surface observation that most adequately represented the surface inflow based on analysis of WSR-88D imagery was then integrated into the sounding. Adjustments were made to the modified soundings to remove any super-adiabatic low level lapse rates or gross changes in moisture or wind velocity. Finally, a number of environmental parameters frequently evaluated for severe/tornadic thunderstorm potential were computed for the discrete and QLCS modes.

3. RESULTS

3.1 CONVECTIVE MODE AND STORM TYPE

A total of 32 significant tornadoes were documented on 10 separate days during the period from 1997-2009. A map showing the geographical distribution of these significant tornadoes within the NWS CR domain is shown in Fig 4. No significant tornadoes were reported across the Great Plains, while from the Mississippi River into the Ohio Valley, QLCSs appear to be the favored mode. Figure 5 shows the total number of significant tornadoes as well as the number of F2/EF2 and F3/EF3 tornadoes for each convective mode. *(Only F2/EF2 and F3/EF3 tornadoes were documented during the 13 year period.)* Significant tornado reports were equally distributed between convective modes with 16 tornadoes each. When compared to QLCSs, discrete cells not only produced the greatest number of F3/EF3 tornadoes by a ratio of 3:1, but they also produced stronger tornadoes with greater relative frequency. Alternatively, QLCSs not only accounted for the most F2/EF2 tornadoes, they tended to produce weaker tornadoes. The QLCS mode cases were further segregated to determine if the significant tornado

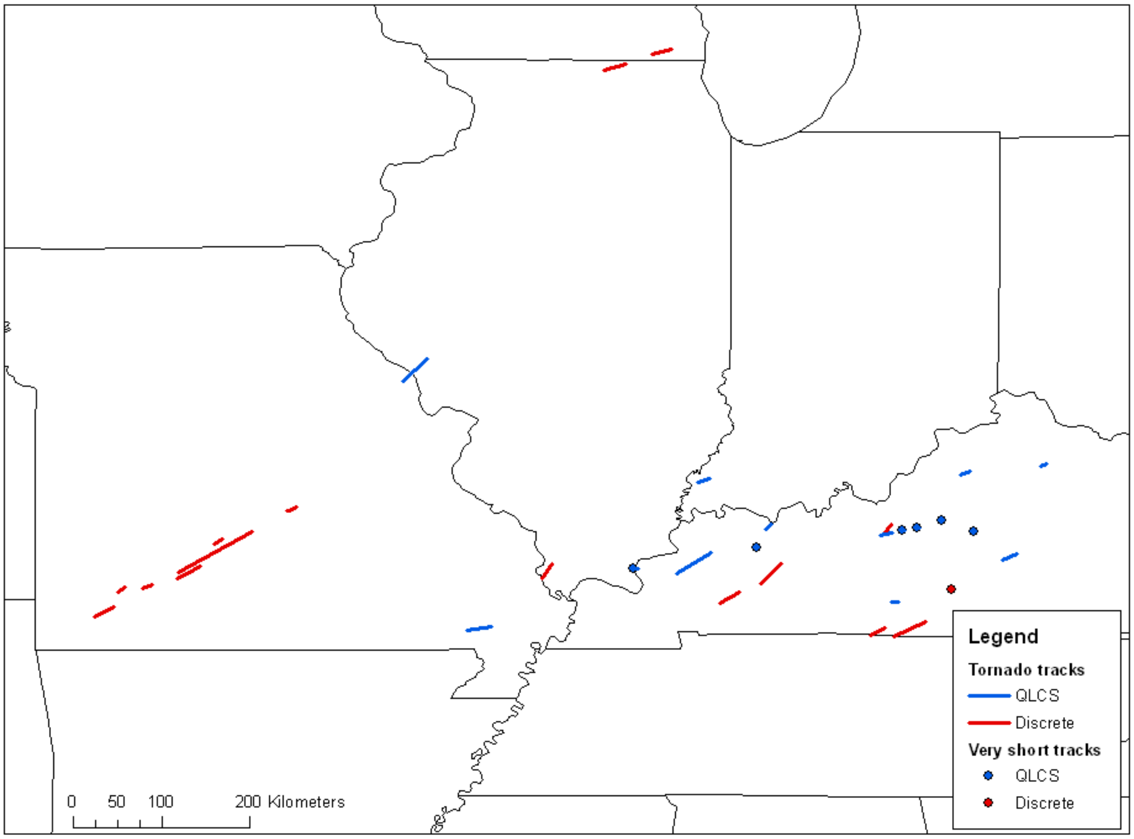

Figure 4. Map of the significant cool season tornadoes during the period from 1997-2009 within the NWS CR domain. Tracks/dots in red correspond to discrete cells while blue corresponds to QLCSs.

resulted from an embedded supercell or a line mesovortex. Of the 16 QLCS tornadoes, 9 resulted from embedded supercells and 7 from line mesovortices (Fig. 6). Since all of the discrete cells were supercells, cumulatively discrete and embedded supercells accounted for 25 of the 32 significant tornadoes or 78%, while line mesovortices accounted for 7 of the 32 or 22% (Fig. 7).

Of the 32 significant tornadoes documented in our study, 25 of them occurred with 6 separate tornado outbreaks (Galway 1975). Table 1 gives details of these outbreaks including a breakdown of the number of significant tornadoes by convective mode. Two of the outbreaks, 7 January 2008 and 5-6 February 2008, contained over half of all the significant tornadoes with 18. Figure 8 shows that during outbreaks, discrete cells produced a greater percentage (56%, 14 of 25) of the significant tornadoes than QLCSs (44%, 11 of 25). Supercells (discrete and embedded in QLCSs) also accounted for the majority of significant tornadoes producing 19 of the 25 (Fig. 9). Cyclic supercells, both discrete and embedded within a QLCS, were common in the larger outbreaks. Interestingly, 6 of the 7 significant tornadoes associated with QLCS line mesovortices also occurred during outbreaks.

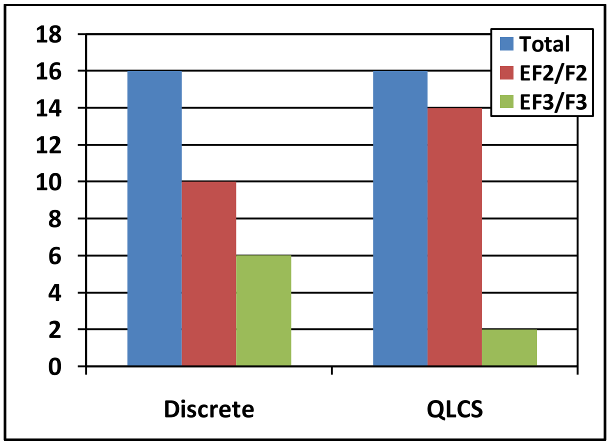

Figure 5. Total number of significant tornadoes and F/EF scale distribution for each convective mode.

Lastly, while it was not the intent of this study, we couldn't help but notice some interesting reflectivity characteristics while examining the radar data for the cases. Cell mergers with the parent tornadic thunderstorm were observed within 20 minutes of significant tornado production for 15 of the 32 tornadoes. Narrow linear bands of radar reflectivity or cells moving from southwest to northeast at speeds well in excess of the mean wind were also observed for 22 of the 32 significant tornadoes. These later radar reflectivity features either merged with the parent thunderstorm on its right flank or moved very close to the inflow region near the time of tornado production. Coleman and Knupp (2008) documented similar reflectivity bands and attributed them to ducted gravity waves. They noted an increase in mesocyclone intensity and tornadogenesis when these bands interacted with several mesocyclonic thunderstorms.

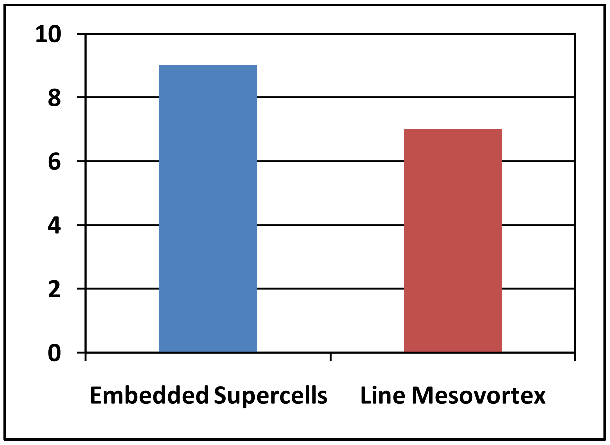

Figure 6. Distribution of QLCS mode significant tornadoes.

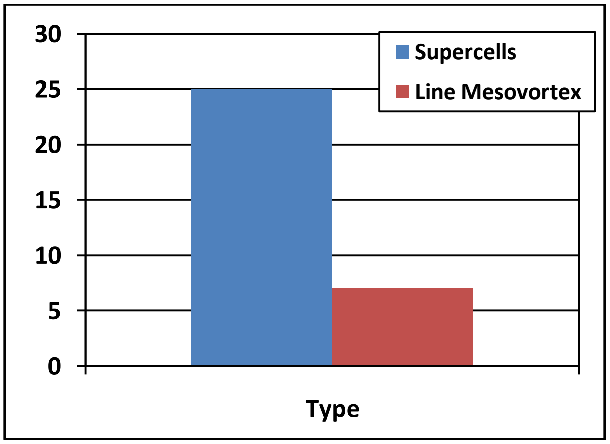

Figure 7. Distribution of significant tornadoes by storm type.

3.2 ENVIRONMENTAL DATA

3.2.1 *Thermodynamic Parameters*

Similar to findings in BG06, the dataset showed lower median Convective Available Potential Energy (CAPE) values than those found in previous studies that contain events throughout the year, namely Thompson et al. (2003 - hereafter T03) that used RUC2 analysis, and Craven and Brooks (2004 - hereafter CB04) that examined a large set of observational soundings. The median most unstable (MU) CAPE for all of the soundings was 703 J/kg, while the median value for MU Convective Inhibition (MUCIN) was only -12 J/kg. For both MUCAPE and MUCIN, there was little difference between the discrete and QLCS modes. The median MU lifting condensation level (MULCL) of 502 meters was well below the values cited by T03 and CB04, with a median value of 502 meters for discrete cells and 467 meters for QLCSs. Similar to findings in BG06, these lower MULCL heights are believed to reflect the higher relative humidity found within the warm sector boundary layer of cool season extratropical cyclones.

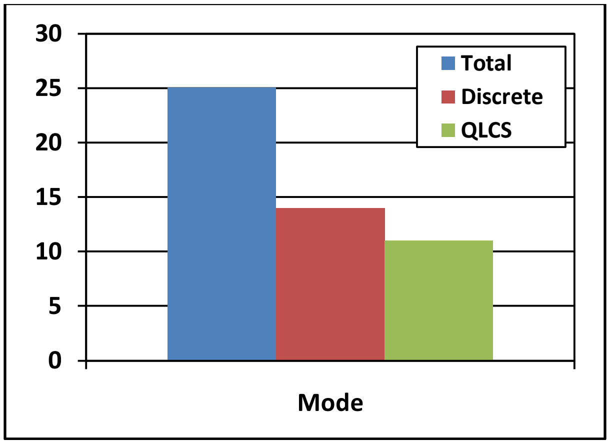

Figure 8. Distribution of significant tornadoes by convective mode during tornado outbreaks.

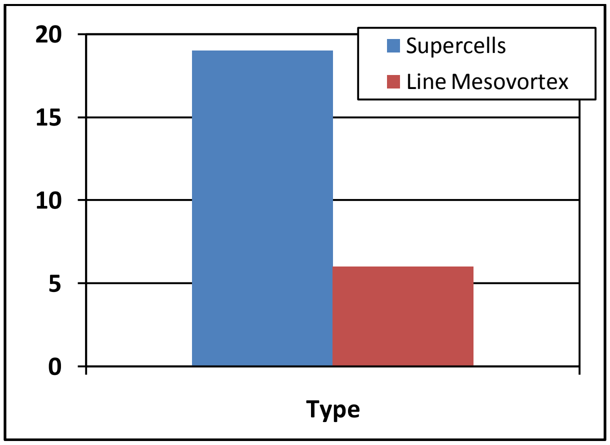

Figure 9. Distribution of significant tornadoes by storm type during tornado outbreaks.

3.2.2 *Kinematic Parameters*

As expected, the bulk wind shear magnitude for 0-1 km and 0-6 km (Fig. 10) exceeds the median values for significant tornadoes found in T03 and CB04. This is most likely because of the stronger wind fields present during the cool season cited in BG06. Both the median 0-6 km shear and effective shear magnitude are notably above the accepted levels needed for updraft rotation (Weisman and Klemp 1982; Thompson et al. 2004). For

Outbreak Date	Total Tornado Count	Total Number of Sig Tors	Number of Sig Tors in NWS CR	Discrete Cells	QLCS	Total Supercells	Line Mesovortex
1/24/97	16	11	1	0	1	0	1
1/22/99	98	28	2	1	1	1	1
12/18/02	9	1	1	1	0	1	0
1/2/06	6	3	3	2	1	3	0
1/7/08	42	6	6	6	0	6	0
2/5-6/08	85	26	12	4	8	8	4

Table 1. Details of tornado outbreaks impacting the NWS CR. The convective mode and storm type statistics listed in the right four columns are only for significant tornadoes (Sig Tors) within the NWS CR.

both the 0-1 km bulk shear magnitude and the effective bulk shear magnitude, there are no significant differences in values for the discrete and QLCS modes. Alternatively, the median 0-6 km bulk shear magnitude of 35 m s^{-1} for discrete cells is 17% greater than the median value for QLCSs.

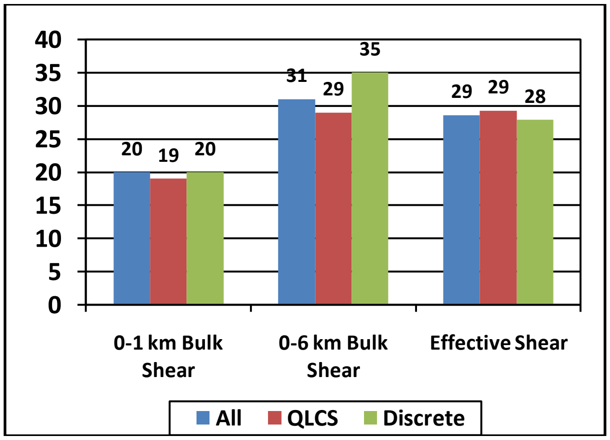

Figure 10. Median shear magnitude in m s^{-1}.

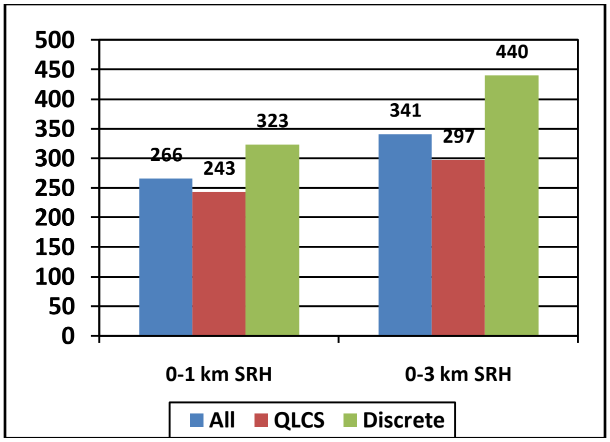

Figure 11. Median SRH magnitude in m^{2} s^{-2}.

There are notable differences in values of storm relative helicity (SRH) between convective modes as identified in Fig. 11. The median value of 0-1 km SRH for discrete cells (323 m^{2} s^{-2}) is 33% greater than for QLCSs (243 m^{2} s^{-2}), while the 0-3 km SRH for discrete cells (440 m^{2} s^{-2}) is 48% greater than the value for QLCSs (243 m^{2} s^{-2}). The median values of storm relative helicity (SRH), taken both individually and collectively for both convective modes, are also well above those found in T03 for supercells with significant tornadoes and those in BG06 for significant cool season tornadoes.

4. SUMMARY AND DISCUSSION

Significant tornado cases (F2/EF2 and greater damage) occurring from December-February were indentified within the Central Region of the National Weather Service for a 13 year period from 1997-2009. A total of 32 significant tornadoes were recorded on 10 separate days. Volumetric radar data from the nearest WSR-88D was used to identify the convective mode *(discrete cell or QLCS)* and storm type of the parent thunderstorm responsible for each significant tornado. The NARR dataset was used to document the environmental conditions in close temporal and spatial proximity to the significant tornadoes. Median values of selected severe weather parameters were then derived for the complete dataset as well as for each convective mode. Below is a summary of the important findings presented in this study:

- Discrete cells and QLCSs produced an equal number of significant tornadoes (16 each). This division agrees well with Thompson et al. (2008) which found nearly identical frequencies of winter significant tornadoes from discrete cells and QLCSs
- Discrete cells were responsible for the greatest number of F3/EF3 tornadoes by a ratio of 3:1, and also generated stronger tornadoes with greater relative frequency.
- QLCSs accounted for the most F2/EF2 tornadoes, while also tending to produce weaker tornadoes.
- For QLCS mode significant tornadoes, embedded supercells produced slightly more tornadoes than line mesovortices.
- Supercells produced the majority of cool season significant tornadoes. Supercells, both discrete and embedded within a QLCS,

accounted for 78% of all the significant tornadoes while line mesovortices accounted for 22%.

- Six tornado outbreaks accounted for a large percentage of the significant tornado count.
- Discrete cells produced a greater percentage of significant tornadoes than QLCSs during outbreaks (56% vs. 44%).
- Supercells (both discrete and embedded within a QLCS) result in roughly three-fourths of significant tornadoes during outbreaks.
- Both discrete supercells and those embedded within a QLCS exhibited cyclic behavior during large tornado outbreaks.
- Cell mergers were observed prior to the occurrence of significant tornadoes nearly half the time.
- Linear bands of reflectivity moving faster than the mean wind interacted with a number of parent thunderstorms.
- The thermodynamic environment for cool season significant tornadoes is characterized by low CAPE and low LCL heights. MUCAPE is nearly identical for discrete cells and QLCSs, while the MULCL height is slightly lower for QLCSs.
- The kinematic environment for cool season significant tornadoes is characterized by high shear and high SRH. The 0-6 km bulk shear for discrete cells is only slightly higher than for QLCSs. SRH values on the other hand are dramatically higher for discrete cells (+33-48%).

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