1.3 CHARACTERISTICS OF COOL SEASON SEVERE ENVIRONMENTS IN THE OHIO VALLEY (1995-2006)

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1. INTRODUCTION

In recent years, severe weather studies (e.g., Rasmussen and Blanchard 1998, Craven et al. 2002, Thompson et al. 2003) have focused on severe and tornadic thunderstorm environments across the contiguous U.S. throughout the year. Other studies have investigated cold season severe weather environments (e.g., Galway and Pearson 1981) across large regional domains. Monteverdi et al. (2003) chose to only examine California severe weather environments which comprised a smaller regional domain. The goal of this study seeks to add to the pre-existing knowledge of cool season severe thunderstorm environments, by focusing on such events within the Ohio Valley region.

Severe weather in the Ohio Valley is typically most frequent in the spring and summer months (Brooks et al. 2000, Brooks et al. 2003). However, the Ohio Valley can occasionally have environments supportive of destructive severe weather during the cool season. According to Galway and Pearson (1981), cool season tornado outbreaks are rare but significant. Two recent well-known examples of this were the deadly 6 November 2005 Evansville, Indiana tornado event and the widespread 10 November 2002 tornado outbreak.

With the installation of the WSR-88D Doppler radar network, it became possible to investigate severe thunderstorms further. Since the early to middle 1990's, the National Weather Service began archiving level II radar data, which is the primary archived radar data that includes reflectivity and velocity, from many Doppler radar sites. The beginning of the 1995-2006 study period coincides with when most Ohio Valley radar sites began archiving level II data. Past studies have examined radar data in order to classify convective storms by convective mode/parent storm type. Trapp et al. (2005) (hereafter T05) investigated climatological distributions of tornadoes by parent storm type and categorized storms as either cell, quasi-linear convective system (QLCS), or "other". Przybylinski et al. (1993) examined high precipitation (HP) supercells for a few select cases and Lee et al. (2006) investigated cell mergers and associated tornado incidence. The radar analysis of our study combined methods from the previous three studies by categorizing tornadic storms by parent storm type, reflectivity morphology, and supercell morphology, respectively.

For the purposes of this study, we defined the Ohio Valley as including Illinois, Indiana, Kentucky, and Ohio and the cool season as October through March. The goal of this study is to better document cool season severe weather episodes and their environments in the Ohio Valley region, which should lead to improved cool season severe weather forecasting and warning operations. The specific focus of this study has three components: 1) to examine severe weather report attributes, 2) to examine the mesoscale environment via proximity soundings, and 3) to determine parent storm type of tornadic storms.

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2. DATA AND METHODOLOGY

The following severe weather report definitions and proximity sounding criteria were utilized to identify severe thunderstorm and tornado proximity sounding cases from the cool season period beginning from October 1995 through March 2006 in the Ohio Valley region.

2.1 Severe Reports

The 1995-2006 severe weather report dataset originated from the National Climatic Data Center's *Storm Data* publication. The severe reports were retrieved from the Storm Prediction Center (SPC) Severe Thunderstorm Database via text files and *Storm Data*, and then compiled and analyzed in a Geographic Information System (GIS).

During the 11-year cool season period 1995-2006, datasets of tornadoes, large hail, and convective wind reports were compiled. We define a tornado day as a 24 hr period beginning at the first reported tornado time and 185 documented tornadoes occurred in 41 days. The study had tornado counts with the following damage rating: 57 F0's, 69 F1's, 41 F2's, 16 F3's, and 2 F4's. As a result, significant tornadoes (F2 or greater) accounted for 31.9% of the study's tornadoes. We defined a tornado outbreak, matching the number (10) used by Galway (1977), as a 24 hr period beginning at first reported tornado time and consisting of 10 or more tornadoes within the Ohio Valley region. It must be noted that an outbreak day had tornado counts only from the Ohio Valley region, thereby reducing the number of larger-scale tornado outbreak days that the Ohio Valley region experienced (i.e. 21-22 January

1999). Also, corrections were made to a limited number of reports in the dataset for tornado times found to be in error. These errors ranged from incorrect dates to half an hour time periods. The large errors involving dates were easily corrected; corrections to smaller time errors were modified to match radar velocity data.

In addition to tornadoes, documented reports of large hail 0.75 in. (1.91 cm) or greater in diameter, severe straight-line wind gusts 50 kts (26 m s^{-1}) or convectively-induced wind damage were analyzed. The sample included 1,339 large hail reports and 2,796 convective wind reports. Using the Storm Prediction Center's classification of significant hail, (2 in. (5 cm) hail in diameter or larger), and significant wind reports, (wind gusts 65 kts (33 m s^{-1}) or greater), resulted in 22 significant hail and 203 significant wind reports.

2.2 Proximity Soundings

To approximate the near storm environment, observed rawinsonde data was utilized in this study. The observed sounding data used in this study was from five upper air sounding sites (ILN, ILX, BNA, DVN, and PIT) located within or near the Ohio Valley study domain. This study utilized similar temporal and spatial criteria for proximity soundings (200 km and +- 3 hr) as Craven et al. 2002 (185 km and +- 3 hr). Such constraints resulted in mesoscale environment approximations not being available for all severe event/tornado days.

The proximity sounding database consisted of 42 tornado soundings and 15 non-tornadic proximity soundings, which were subjectively quality controlled for erroneous data. As to not bias the findings toward any particular day or outbreak, rawinsondes utilized in this study were limited to one for single tornado days (or multiple tornado days with only F0 tornadoes) and two soundings for multiple tornado days. The exception was the inclusion of representative soundings for all F3+ tornadoes, hence 3 soundings for 29 March 1997/00 UTC. If more than one tornado occurred on a given day, priority was given to sounding classification by F-scale rating and then closest spatial/temporal proximity to the rawinsonde location. For non-tornado days, the temporal/spatial proximity location (200 km and +- 3 hr) was based on a time/location closest to the initial onset of multiple hail/wind reports, provided a relatively concentrated (i.e. 5+ reports within 150 km and ~6 hours) area of hail and wind reports. Non-tornado proximity soundings were limited to inclusion of one rawinsonde for a given rawinsonde site per day. The observed soundings in this study were modified for surface temperature, dewpoint, and wind speed/direction of the nearest inflow surface (ASOS/AWOS) observation.

2.3 Tornadic parent storm classification

A radar dataset, consisting of parent storms for 166 tornadoes associated with F0 to F4 damage rating, was classified according to radar signatures at tornado touchdown time. The WSR-88D archived level II radar data used in the analysis of this study was acquired from the National Climatic Data Center (NCDC) or retrieved from radar files stored in a Weather Event Simulator (WES) computer at the National Weather Service office in Indianapolis, Indiana. GRlevel2 radar software program or WES D2D archived radar data were used to examine the high resolution radar data. The radar dataset included data from 17 different radar sites (KLOT, KILX, KLVX, KPAH, KJKL, KHPX, KILN, KCLE, KDTX, KIWX, KIND, KVWX, KLSX, KMRX, KNQA, KOHX, KPBZ). Despite insufficient, incomplete, or no archived level II data being available for some events, parent storms for 166 of 185 tornadoes were able to be analyzed. When archived level II radar data was available, animations of complete volume scans of reflectivity and velocity data signatures were used, to aid in the parent storm type analysis of tornadic thunderstorms just prior to and immediately after tornado touchdown time.

2.3a Parent storm type

Parent storm type was determined by examining radar reflectivity structures (e.g. WER, BWER, hook echo, bow echo) and storm-relative velocity to classify the parent storm as a supercell, quasi-linear convective system (QLCS), or "other". Examples of storms classified as "other" include isolated non-supercells, multicells, or storms with insufficient data (e.g., indeterminate radar signatures, radar sampling limitations).

The definition of a supercell was based on the National Severe Storms Laboratory mesocyclone detection algorithm (Stumpf et al. 1998). A supercell is convective storm possessing a deep and persistent mesocyclone through at least 1/4 of the storm depth. Also, mesocyclone shear values must have met or exceeded the minimal threshold for shear (based on the 1.85 km (1.0 nm) NSSL MDA nomogram through 6.48 km (3.5 nm) (Andra et al. 1997) and persisted for at least 10 minutes. It is worth mentioning that low-topped mini supercell mesocyclones are difficult to detect especially at medium and long ranges due to a number of factors such as sampling and range limitations (Brown and Wood 1999) and size and strength of the mesocyclone (Burgess et al. 1995, Grant and Prentice 1996). Nevertheless, we used the 1.85 km nomogram to try and identify the weaker spectrum of tornadic supercell storms.

A tornadic QLCS was defined as tornadic thunderstorms appearing to be associated with a quasi-linear area of continuous reflectivity greater than 40 dBZ, distributed over a distance greater than 50 km in length and either lacking a radar detectable mesocyclone or clearly originating from non-supercells (e.g., bow echoes). A storm appearing discrete with regard to reflectivity but without a radar detectable mesocyclone was classified as "other". Inevitably there may have been a few cases classified as "other" due to radar sampling and range limitations, which can reduce the radar's ability to resolve sufficient shear. One example of this occurrence was the 7 December 2004

Decatur Co., Indiana low-topped supercell with an echo top around 6.4 km AGL (21,000 ft); however the nearest radar (KIND) did not archive level 2 data so data from KILN was used instead. As in previous studies of storm classification, we acknowledge that our storm classification like other similar studies (e.g., T05, Lee et al. 2006) at times, is unavoidably subjective.

2.3b Reflectivity morphology

For those storms classified as supercells, we further stratified supercells as being discrete or embedded in a line, based upon somewhat arbitrary radar reflectivity criteria. We defined a discrete supercell as being relatively isolated from any quasi-linear region of reflectivity. Embedded supercells were classified as a supercell storm located within a quasi-linear area of continuous reflectivity at the lowest volume scan greater than 40 dBZ and distributed over a distance greater than 50 km. These cases may be more well-known as being line segments with embedded supercell(s). Embedded supercells were further classified as either embedded within quasi-linear reflectivity (QLR) (Fig. 1) or merging with an area of QLR (Fig. 2) within 15 minutes of reported tornado touchdown time, consistent with Lee et al. (2006).

2.3c Supercell depth

The tornadic supercells identified in our sample were also classified as “deep” or “shallow” based on echo top height. Despite these inherent limitations we examined 90 supercells. Cognizant of echo top height limitations and sampling errors discussed in Maddox et al. (1999) and Delobbe, (2005), (e.g. cone-of-silence, errors resulting from long range, large vertical reflectivity gradients, echo height measurements from one radar), we used NEXRAD Legacy echo top heights from one radar because the GRlevel2 radar viewing software used this echo top algorithm for echo top identification. The echo tops of supercells were analyzed using volume scan data that was closest in time immediately prior to tornado touchdown time. Storms less than or equal to 32,000 ft (9.75 km) were considered low-topped or shallow per Davies (1993) and Kennedy (1993). Whereas supercells possessing echo tops greater than 32,000 ft (9.75 km) are considered “deep” supercells. In the few cases that were insufficiently sampled by the nearest radar because of cone-of-silence limitations, priority was given to sampling echo tops by the second closest available radar or by using echo top data from the nearest radar a few volume scans prior or after tornado touchdown time in the above mentioned order.

3. RESULTS

3a. Severe Reports

According to our database, 185 tornadoes occurred in the Ohio Valley region during the 1995-2006 cool seasons. There were six outbreak days (defined as 10 or more tornadoes) amongst the 41 tornado days. The outbreak days were associated with 100 of the 185 (54.1%) tornadoes. Interestingly too, were the percentages of significant tornadoes produced on an outbreak day (35.0%) compared to the overall dataset’s percentage of significant tornadoes (31.9%). As a result, 59.3% of the dataset’s total number of significant tornadoes occurred in the six outbreak days. Additionally, the six outbreak days accounted for approximately 24% of the non-tornado severe reports and 18% of the non-tornado significant severe reports. More tornadoes occurred in November than any other cool season month (Fig 3). November was found to be the secondary frequency peak for tornadoes in the Ohio Valley (1995-2005).

3b. Proximity Soundings

Based upon the proximity observed soundings modified for surface conditions, the NSHARP sounding analysis program (Hart et al. 1999) was used to analyze particular thermodynamic and kinematic parameters associated with Ohio Valley cool season severe weather cases. Similar to the results from the Doppler radar data portion of the study, derived environment data confirmed a tendency for relatively low topped storms during the cool season, with equilibrium (EL) heights predominately between 25,000 and 35,000 ft. Profiles with relatively modest instability (MLCAPE values 1000 J/kg or less) and strong vertical shear (45-50 kts or greater) majority of cases within the dataset. For even strong tornado episodes and regional severe weather outbreaks during the cool season, 100 mb MLCAPE values were typically not higher than 500-1000 J/kg (Fig. 3).

Further comparisons were made in an attempt to discriminate the environments of significant tornadoes (F2 and greater), weak tornadoes (F0-F1), and non-tornadic (hail and wind) severe storms. Conventional parameters such as CAPE (Fig. 3 - 100-mb mixed layer and most unstable parcel), and deep layer (0-6 km) bulk shear (Fig. 4) revealed a tendency for progressively higher values of CAPE and vertical shear from hail/wind, to weak tornadoes, to significant tornadoes. Similar tendencies were noted for composite parameters such as SPC's Supercell Composite Parameter (SCP - not shown) and SPC's Significant Tornado Parameter (STP - Fig. 5) (Thompson et al. 2003). Greater values of 0-3 km and 0-1 km Storm Relative Helicity (SRH – Figs. 6 and 7), 0-3 km CAPE (not shown), and 0-1 Vorticity Generation Parameter (VGP – Fig. 8) exhibited some discrimination ability between report types, especially with respect to significant tornadoes vs. non-tornadoes. Derived parameters such as LCL height, LFC height and surface based/mixed layer CIN (not shown) appeared to exhibit little or no distinction between tornadoes (strong or weak) vs. non-tornadoes for the Ohio Valley cool season cases. Even where trends were noted, our results indicate that different event types can occur in similar mesoscale environments, and considerable uncertainty exists when attempting to specify events based on environmental parameters from rawinsondes.

3c. Tornadic parent storm type

Classifying parent storm type was possible for 166 of 185 tornadoes in the database using the methodology presented herein. Supercells produced 54% of these tornadoes, 43% were produced by QLCS, and 2% by storm types classified as “other” (see Table 1). From the supercell cases, we further examined storm reflectivity and supercellular morphologies. Discrete supercells were responsible for 70% of the supercell tornadoes and embedded supercells were associated with 30% of tornadic supercells (Table 2). Also, from the sample of embedded tornado-producing supercells, 37% were classified as supercells merging with quasi-linear reflectivity (QLR) at the time of documented tornado touchdown time, and 63% were classified as not merging with QLR (Table 3). We found that in many of the supercell-QLR merging cases, the base reflectivity’s of the storms with different morphologies merged prior to their corresponding base velocities. It is worth mentioning that storm-scale interactions between supercell and QLCS circulations seem to have qualitative relationship based on radar velocity data. However, just how, if any relationships exist; between tornadogenesis and parent storm type evolution resulting from cell mergers is beyond the scope of this study. Lastly, shallow tornadic supercells comprised 14% of the tornadic supercell cases (Table 4).

This study’s percentage of tornadoes produced by QLCS’s was noticeably higher at 43% compared to 18% found by T05 for all tornadoes in the contiguous United States during the 1998-2000 period. Examining tornado days according to parent storm type, we found the percentage of tornado days for QLCS, supercell, and combinations of both modes yielded 61%, 46%, and 27% respectively. In summary, our results support T05’s conclusion that QLCS tornadoes appear more likely to occur in the cool season.

Lastly, are the dataset’s summary statistics of tornadoes based on tornadic parent storm type. From the study, higher percentages of weak tornadoes (F0-F1) were associated with QLCS’s (81.9%) than supercells (52.2%) (Table 5). These percentages do not disagree with T05’s suggestion that a weak tornado associated with a QLCS is more probable than a weak tornado associated with a discrete cell. Additionally, percentages of significant (F2-F4) tornadoes by supercell and QLCS were 47.8% and 18.1% respectively.

4. SUMMARY AND DISCUSSION

These findings indicate cool season severe weather in the Ohio Valley is relatively uncommon but when it occurs, it is sometimes in the form of a regional tornado outbreak. Also, it is hoped that this study may aid operational forecasters in forecasting of cool season severe environments in the Ohio Valley, through increased knowledge about past cool season severe weather frequency and magnitude. In particular, knowing that an Ohio Valley cool season tornado outbreak day can be just as significant, if not in some cases more so, as their warm season counterparts can improve the situational awareness of forecasters.

In this study of cool season severe weather and its incipient environments, we have examined 1) severe report attribute data, 2) environmental soundings, and 3) parent storm type of tornadic storms. The results raise questions about null severe environments and parent storm type associated with null tornadic environments. In future work, we plan to examine 1) null severe environments 2) cool season severe environments found in other regions outside the Ohio Valley and 3) parent storm type of non-tornadic severe storms.

Acknowledgements. The authors would like to thank John Ogren (NWS Indianapolis, IN) and Steve Weiss (SPC) for supporting this work. Additionally, John Kwiatkowski (NWS Indianapolis, IN) and Steve Weiss provided valuable, thought provoking comments about how to improve this manuscript. Finally, we have benefited from discussions with Rich Thompson (SPC), Ariel Cohen (University of Oklahoma), Jonathan Davies (private meteorologist), Theodore Funk (NWS Louisville, KY), and James Ladue (WDTB).

5. REFERENCES

References available upon request.

6. ILLUSTRATIONS AND TABLES

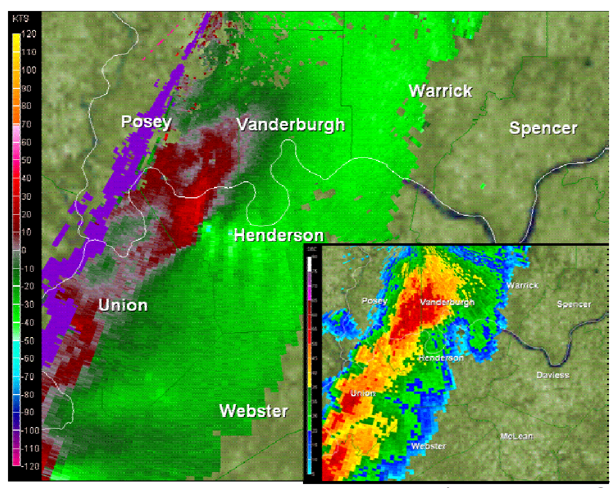

Fig. 1. Radar storm relative velocity (0.5˚) at 0738 UTC 06 November 2005 showing Evansville, Indiana embedded supercell within QLR near tornado touchdown time. Green inbounds, red outbounds. Overlaid image is radar reflectivity (0.5˚) from KVWX.

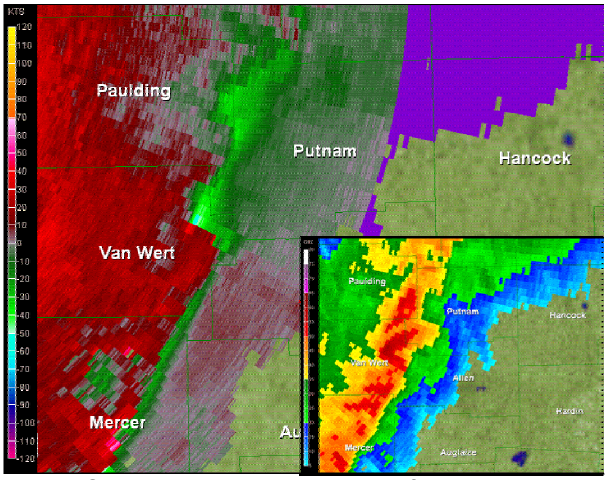

Fig. 2. Storm relative velocity and reflectivity as Fig. 1 from KIWX at 2330 UTC 24 October 2001 showing Van Wert Co., OH embedded supercell merging with QLR near tornado time.

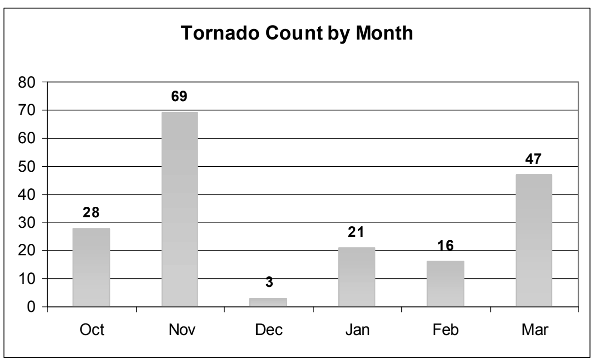

Fig. 3. Tornado count by month.

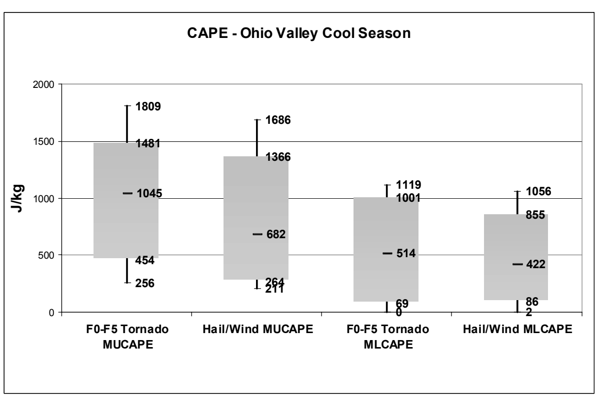

Fig. 3. Most Unstable (MU) CAPE and 100-mb mixed layer (ML) CAPE values for tornadoes (F0-F5) and hail/wind (non-tornado) reports during the cool season in the Ohio Valley. On the box and whiskers diagram, surrounding the median value, the box denotes the 25th to 75th percentiles, while the outer whiskers represent the 10th and 90th percentiles.

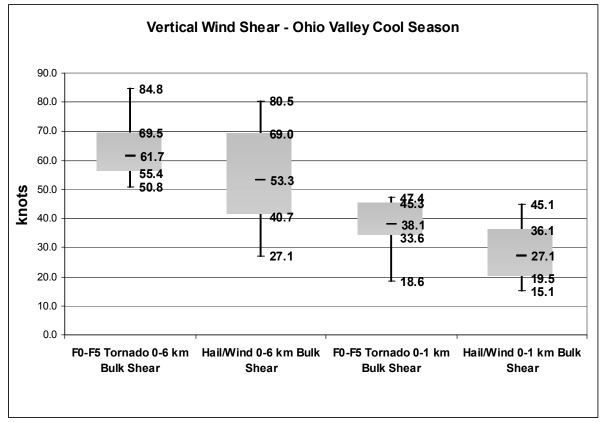

Fig. 4. Same as in Fig. 3, except values (in kts) of 0-6 km and 0-1 km bulk shear values for tornadoes (F0-F5) and hail/wind (non-tornado) reports during the cool season in the Ohio Valley.

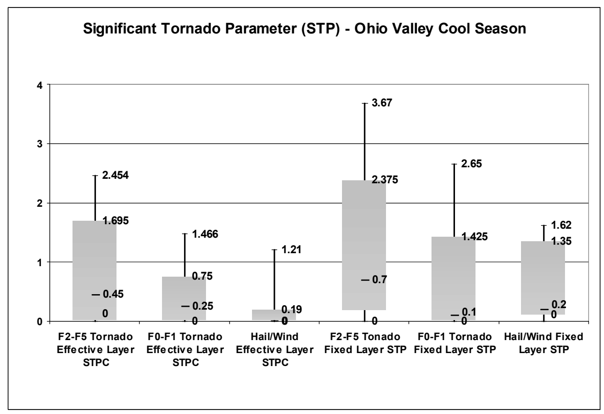

Fig. 5. Same as in Fig. 3, except values of the Significant Tornado Parameter for significant tornadoes (F2-F5), weak tornadoes (F0-F1), and hail/wind (non-tornado) reports during the cool season in the Ohio Valley. Left half of the diagram is the STPC utilizing an effective inflow layer with CIN, while the right half is the fixed layer STP.

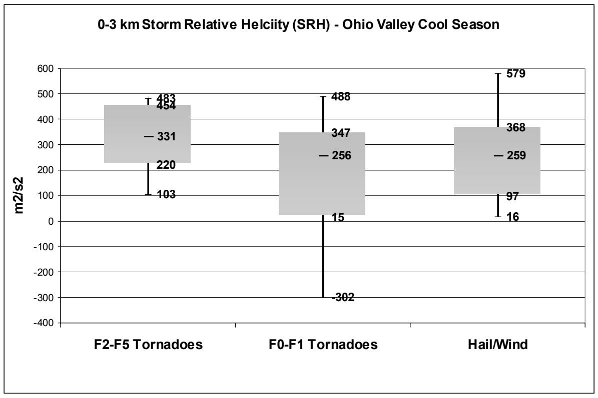

Fig. 6. Same as in Fig. 3, except 0-3 km Storm Relatively Helicity (SRH) for significant tornadoes (F2-F5), weak tornadoes (F0-F1), and hail/wind (non-tornado) reports during the cool season in the Ohio Valley.

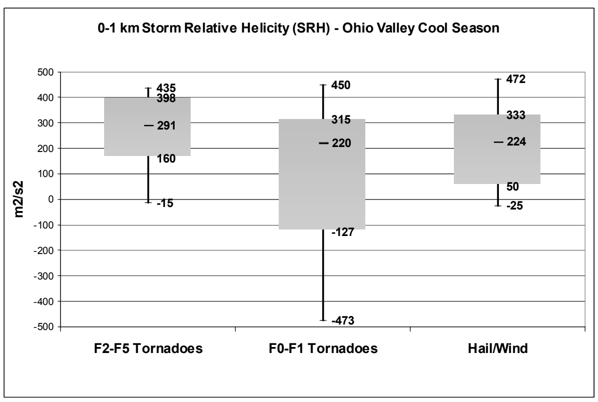

Fig. 7. Same as in Fig. 3, except 0-1 km Storm Relatively Helicity (SRH) for significant tornadoes (F2-F5), weak tornadoes (F0-F1), and hail/wind (non-tornado) reports during the cool season in the Ohio Valley.

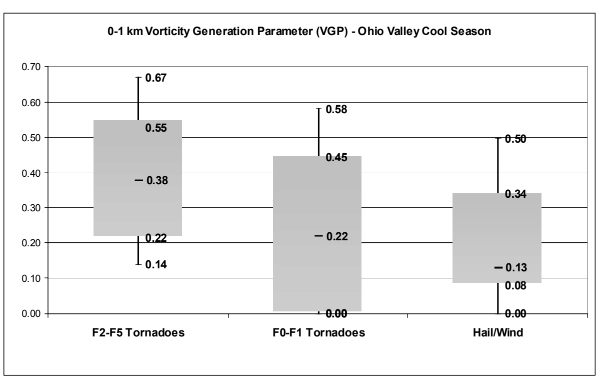

Fig. 8. Same as in Fig. 3, except 0-1 km Vorticity Generation Parameter (VGP) for significant tornadoes (F2-F5), weak tornadoes (F0-F1), and hail/wind (non-tornado) reports during the cool season in the Ohio Valley.

TABLE 1. Comparison of tornadic parent storm type, archetype, and morphology.

Type	Number	Total Percentage
Supercell	90	54.2%
QLCS	72	43.4%
Other	4	2.4%

TABLE 2. Comparison of tornadic supercells.

Type	Number	Percentage
Discrete	63	70.0%
Embedded	27	30.0%

TABLE 3. Comparison of embedded tornadic supercells.

Type	Number	Percentage
Within QLR	17	63.0%
Merging w/ QLR	10	37.0%

TABLE 4. Comparison of deep versus shallow tornadic supercells using echo top height.

Type	Number	Percentage
Deep	77	85.6%
Shallow	13	14.4%

TABLE 5. Comparison of tornadic parent storm type, and weak (F0-F1) tornadoes.

Type	Weak Tornadoes	Percentage
QLCS	59	81.9%
Supercell	47	52.2%