MESOCYCLONE CHARACTERISTICS OF MINI SUPERCELL THUNDERSTORMS

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1. INTRODUCTION

As installation of the operational WSR-88D network nears completion, new data sets are becoming available for the investigation of supercell thunderstorms. This growing archive of Doppler radar data is crucial to the continued investigation into the broad spectrum of structures of supercells.

Initial observations from some of the first network WSR-88Ds have revealed some interesting characteristics of “low-topped” or “mini” supercell thunderstorms (Burgess et al, 1995). These supercells are described as typically smaller, both horizontally and vertically, than those common to the Great Plains region. Radar researchers have confirmed modeling studies such as Wicker and Cantrell (1996), which showed that mini supercells do indeed have the same attributes (albeit smaller) as the larger Great Plains types. These attributes include hook echoes, WERs, BWERs, and mesocyclones. The mesocyclones appear to have lesser rotational velocities, smaller diameters, and shallower depths when compared to the often studied mesocyclones in the Plains region.

Accurate assessment of mesocyclone strength criteria remains one of the most crucial elements in decision-making for issuing tornado warnings in the National Weather Service. Since a majority of mesocyclones do not produce tornadoes (Burgess and Lemon, 1991), one of the questions for warning forecasters has been, “at what level of mesocyclone core intensity do I issue a tornado warning?”

Certain recognition criteria from studies of Oklahoma storms containing mesocyclones have been established using shear, persistence, and vertical extent. Guidelines for issuing warnings (both severe thunderstorm and tornado) have then been suggested from evaluating the mesocyclone strength nomogram (Figure 1) (Andra et al, 1994). This nomogram explicitly uses only rotational velocity as a function of range and assumes a 3.5 nm core diameter and mid-range velocity values in its computations. (Note: other nomograms have been generated based on smaller diameter mesocyclones; the net effect being more sloped lines than in Figure 1)

This study will examine characteristics of 16 tornado-producing mesocyclones associated with mini supercells from WSR-88D data studied over the past few years at the Operational Support Facility (OSF). The specific purpose of this study is to show which characteristics have the most operational utility as tornado predictors in mini supercells.

2. DATA ANALYSIS

The current WSR-88D data set built upon many of the cases already included in the study by Burgess et al. (1995), and possesses the same sampling limitations as described therein. Base data from six additional cases were analyzed using the

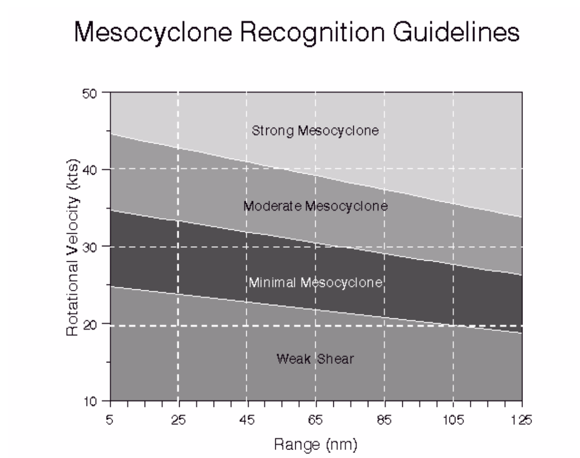

Figure 1 Mesocyclone Recognition Guidelines (assumes a 3.5 nm diameter).

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WSR-88D Algorithm Testing And Display System (WATADS, Storm Scale Research and Application Division, NSSL, 1995), where Archive Level II data were available. The remaining "new" case (KDAX 03/23/95) was analyzed using Archive Level IV data.

The set of 16 data cases originated from 8 different radar sites (KPUX, KIWA, KLWX, KDAX, KHGX, KRME, KCAE, KVNX) and were associated with mesocyclones that produced tornadoes ranging from F0 to F3 intensity. Echo tops for the parent storms were generally in the 25-30 kft range. Most of these storms occurred near the radar. The average range was < 30 nm (56 km), so sampling considerations were not much of a problem.

To evaluate characteristic trends in mesocyclone evolution, each case was stratified temporally by measuring mesocyclone-related parameters from five volume scans prior to tornado touchdown time to one volume scan after touchdown time. The parameters measured each volume scan (approximately 6 minutes apart) were then averaged over all of the cases that contained at least partial data for a given parameter. The parameters included were: low-level mesocyclone diameter, low-level rotational velocity, maximum rotational velocity, maximum shear, height of maximum rotational velocity, and height of maximum shear.

The most recent version of the NSSL Mesocyclone Detection Algorithm (MDA) (Stumpf and Marzban, 1995) was used through WATADS to measure the aforementioned mesocyclone parameters for the six additional cases. This was done in order to minimize time in analyzing and processing the radar data. Some missing data and errors are introduced in this process so care was taken to ensure that the algorithm output is accurate. Archive Level II base data from a common case (KLWX 04/16/93) was analyzed on both display systems (WSR-88D PUP and WATADS) and comparable differences for the parameters used for this study were considered minimal.

3. RESULTS

Figure 2 shows the trend of average lowest altitude diameter of the mesocyclone from T-5 to T+1. There

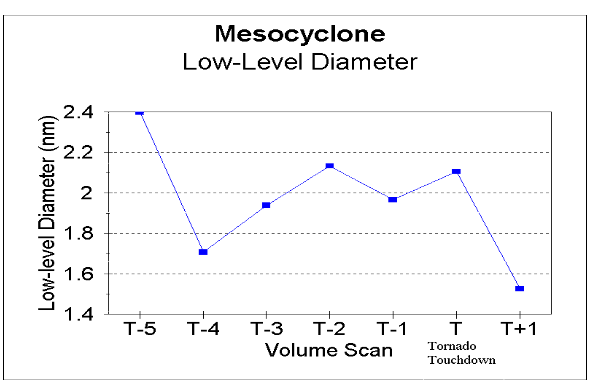

Figure 2 Lowest level mesocyclone diameter (nm) for 16 mini supercell cases.

was a sharp decrease from 2.4 nm (4.4 km) at T-5 to 1.7 nm (3.1 km) at T-4, but no other significant decrease in low-level diameter until immediately after tornado touchdown time. It is important to note that the average diameter at lowest levels of mini supercell mesocyclones was smaller (by 1.5 nm) than the assumed 3.5 nm diameter for the OSF mesoscale recognition guideline nomogram.

Figure 3 shows the average mesocyclone base height (lowest altitude of mesocyclone circulation) . From T-5 to T-3, a decrease from 6.5 kft (2 km) AGL to 4.5 kft (1.4 km) was noted. A more gradual descent occurred through T+1. Figure 4 shows the average lowest level rotational velocity (Vr) during the time from T-5 to T+1 for 16 cases of mini supercell mesocyclones. Values increased

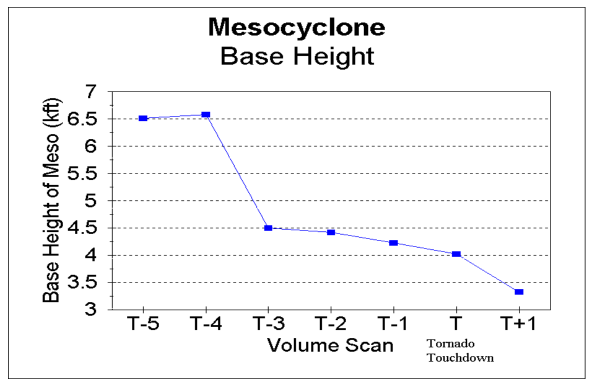

Figure 3 Mesocyclone base height (kft) for 16 mini supercell cases.

from 20.8 kt (10.7 ms^{-1}) at T-3 to a peak of 24.8 kt (12.8 ms^{-1}) at T (tornado touchdown time).

Figure 5 depicts the average maximum Vr (for all levels) for the 16 data cases. Values increased from 28.4 kt (14.6 ms^{-1}) at T-3 to 32.7 kt (16.9 ms^{-1}) at T-1. It is noteworthy that the peak value of max Vr occurred at T-1, with a sharp decrease thereafter. It is also interesting to note that the range of values for max Vr fall into the "minimal

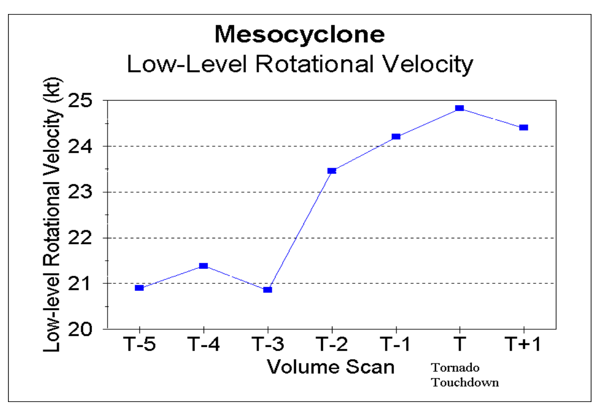

Figure 4 Lowest level rotational velocity (kt) for 16 mini supercell cases.

mesocyclone" category on the standard OSF mesocyclone strength nomogram (Figure 1). The average height of max Vr (Figure 6) decreased steadily from 9.3 kft (2.8 km) AGL at T-5 to 5.8 kft (1.8 km) at T-2. The minimum height of 5.5 kft (1.7 km) occurred simultaneously with tornado touchdown time. Note that at a 23 nm range from the radar (which was the average distance of the mesocyclone at time T), the centerline of the lowest

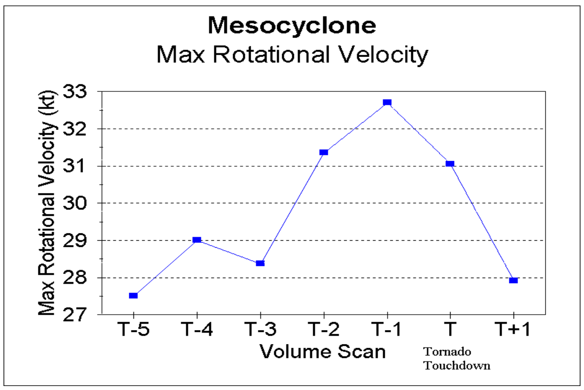

Figure 5 Maximum rotational velocity (kt) for 16 mini supercell cases.

elevation angle of the radar beam is about 2 kft AGL. Thus, the radar was adequately sampling the

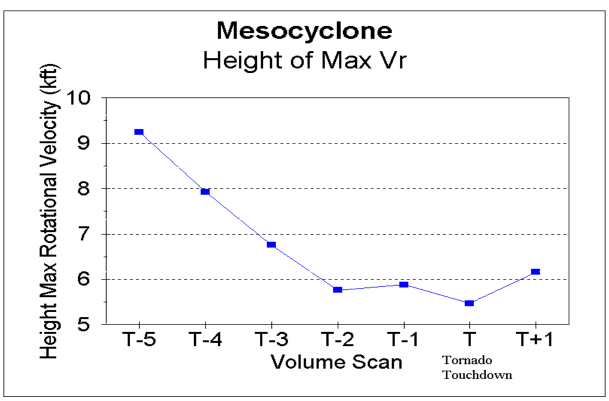

Figure 6 Height of maximum rotational velocity (kt) for 16 mini supercell cases.

mesocyclone characteristics in these data cases.

Figure 7 shows the trend for average maximum shear for this set of mini supercell mesocyclones. The peak for maximum shear ($15 \times 10^{-3}s^{-1}$) correlated exactly with tornado time. Max shear values doubled between T-5 and T as rotational velocities increased and mesocyclone diameter "tightened up". Sharp decreases in shear values were noted immediately after tornado touchdown.

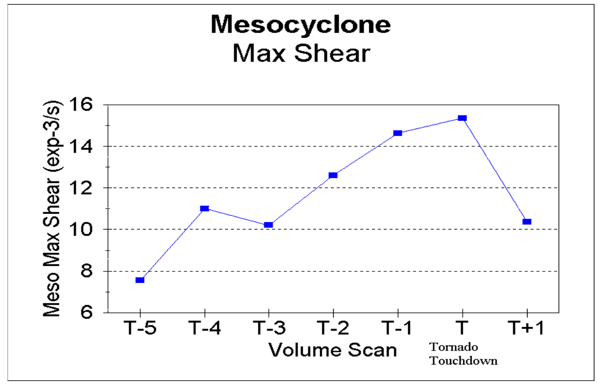

Figure 7 Maximum shear ($x10^{-3}s^{-1}$) for 16 mini supercell cases.

Figure 8 shows the average height AGL (in kft) of the max shear for the 15 mini supercell mesocyclones. A significant drop from over 9 kft (2.7 km) to around 6 kft (1.8 km) was noted from T-5 to T-4. After that, values remained nearly constant with

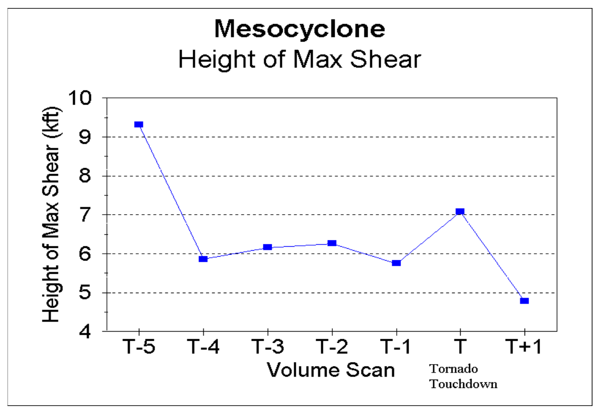

Figure 8 Height of max shear ($x10^{-3}s^{-1}$) for 16 mini supercell cases.

only a slight increase to 7.1 kft (2.2 km) at tornado time, followed by a decrease to just under 5 kft (1.5 km) at T+1.

The graph showing mesocyclone depth, as determined from the two algorithms, is not shown. Values varied sporadically between 9.6 kft (2.9 km) and 7.9 kft (2.4 km) and provided little predictive value by itself as a precursor signal to tornado touchdown time.

4. CONCLUSIONS

Most of the mini supercell mesocyclone characteristics examined showed some operational utility as tornado predictors. The resulting trends shown here, for the most part, compare favorably to previous studies involving tornado-producing mesocyclones. The values measured at T-5 to T+1 are similar to values during the mature stage of mesocylone evolution obtained in the study of mini supercells by Burgess et al., (1995).

The characteristic trend which showed the best correlation to tornado touchdown time in these 16 cases was max shear, which doubled in magnitude in approximately 24 minutes during the period from five volume scans prior to tornado time to 1 volume scan before tornado time. The average height of this max shear during this period dropped from near 9 kft (2.7 km) to near 7 kft (2.1 km). This is a possible indication that tornadoes in a given environment can initiate without the strongest shear being detected in the lowest elevation slice (at least from the WSR-88D).

As expected, a trend toward decreasing mesocyclone base height was a precursor indicator to tornado initiation. In addition, low-level rotational velocity (Vr) and max Vr, both showed marked increases in magnitude from T-5 to near tornado time. Average values of max Vr and lowest-level Vr fell into the “minimal” category on the OSF Mesocyclone Strength Nomogram. Thus, in situations where mini supercells are possible, tornado warnings might be justified with mesocylones indicated in this category. The height of max Vr descended steadily from 9 kft to around 5.5 kft at tornado time, suggesting that this parameter could also be used as a possible precursor indicator for tornado initiation.

Low-level diameter of the mesocyclone was not much of a precursor indicator since the height of the max shear and max Vr was frequently located above the lowest elevation slice of the radar. Mesocyclone depth was also not considered to have much operational utility as a precursor to tornado initiation. It was significant, however, that the average depth was significantly less than the 10 kft depth criteria associated with recognition studies of Oklahoma tornado-bearing mesocyclones.

More cases of mini supercell thunderstorms are needed to establish confidence in proposing additional warning guidelines on tornadoes associated with this type of phenomena. Recommendations have been made to use an Integrated Rotational Strength (IRS) index which, when added to the current Mesocylone Algorithm used in the WSR-88D, will help to better assess the relative strength of mesocylone circulations (Lee, 1996). This strategy of improving the Mesocylone Algorithm will help to decrease the False Alarm Ratio (FAR). Optimizing adaptable parameters on the WSR-88D, such as decreasing the minimum number of Threshold Pattern Vectors (TPV) from 10 to 6, has also been shown to improve performance for detection of circulations with smaller horizontal and vertical extents (TPV of 6 was used in this study).

Future software builds of the WSR-88D may be able to incorporate trend data of mesocyclone characteristics such as is used in WATADS. Evaluating these trends of a severe storm’s characteristics in real-time will provide operators the necessary information which, in conjunction with a complete analysis of all available data resources, (satellite imagery, surface observations, profiler data, spotter information, etc.) will provide an improved and accurate warning detection method.

5. ACKNOWLEDGMENTS

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