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The Existence of Descending Reflectivity Cores in Rear-Flank Appendages of Supercells

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1. Introduction

Three-dimensional analyses of radar data from VORTEX by Rasmussen et al. (2006) revealed that in several cases, development of a hook echo appendage was preceded by the descent of a reflectivity core pendant from an echo overhang. Descending from three to six km AGL, these reflectivity cores typically took five to fifteen minutes to descend to the lowest elevation tilt used by the WSR-88D radar. This feature either helped create or intensify the reflectivity in an already present rear-flank echo appendage. Called the Descending Reflectivity Core (DRC), it is often spatially associated with enhanced rear-to-front, low-level flow, on Doppler radar, and is presumed to be associated with outflow from a downdraft. Because the rear-to-front flow is spatially isolated, it is sometimes associated with counter-rotating vortices.

In Rasmussen et al. (2006), the DRC typically occurred prior to tornadogenesis hence making it a topic worthy of further study. With its temporal and spatial occurrence around tornadoes, the DRC could be related to the onset of tornadogenesis. If this is validated or quantified, the DRC could have use for warning decision making for tornadoes. Analysis of the DRC also may be vital in obtaining a more complete understanding of the morphology of the rear-flank appendage of the supercell and related tornadogenesis.

The motivation for this paper is to serve as an extension to Rasmussen et al. (2006). Sections 2-4 quantify how often DRCs occurred within a larger sample of supercells. Methodology of this work is presented in section 2, results in section 3, and a brief discussion in section 4. With the inclusion of tornadic supercells, their relationship to tornadoes is ascertained. By looking at a large quantity of supercells, several preliminary observations are made on differences between DRCs in the study. Section 5 discusses the first visual observation of a DRC which was documented during the course of this work by the author and several other storm observers in Oklahoma on 6 June 2005. Section 6 offers a summary of the paper with key results highlighted.

2. A Characterization of DRCs

To assemble a climatological sample of DRCs, a systematic process was necessary to make the study as objective as possible. This was accomplished by defining the domain for the dataset, selecting storms of interest, and finally, analyzing radar data to locate DRCs.

a. Domain

WSR-88D Level II data from NCDC were used to find storms of interest. Only radars in and around the Southern Plains were considered, which includes those within Kansas, Oklahoma, and northern Texas. Because the DRC is an echo that evolves with height, it is necessary to utilize data from several elevation angles. By limiting the domain to the 20-100 km range, the lowest data were no more than 1.5km AGL and the data extended upward to at least six km AGL for all storms.

To obtain a reasonable sample of supercells, radar data from the month of May in the years 2001-2005 were examined. Level II radar data were acquired +/- six hours of either tornado reports or hail reports ≥ 2.54 cm in diameter obtained from the NCDC Storm Event Database. This process was expedited by quickly filtering storm reports through the use of software such as ArcView-GIS (ESRI 2000) and SeverePlot (Hart 1993).

b. Storm selection

To make storm selection as objective as possible, a set of criteria was developed to classify those supercells that should be considered. Supercells were chosen for study by using a combination of both radial velocity and reflectivity signatures on radar as discriminators. While no condition was applied based off mesocyclone strength, storms had to contain vertical continuity of cyclonic shear over at least three elevation tilts. This region of shear had to lie within the area one would expect a mesocyclone, to the right of the forward-flank downdraft (FFD) and centered near the echo vault. In addition, these storms had to contain a persistent (existent during several volume scans) rear-flank appendage; a necessary requirement for the DRC. To minimize subjectivity, Forbes' (1985) classification scheme for rear-flank appendages of supercells was used. This scheme was originally implemented to discriminate which echoes were associated with tornadoes during the super-outbreak of 3-4 April, 1974. To qualify as an appendage, the echo protrusion called the appendage had to be oriented 40 deg or greater from the storm motion vector. Finally, only isolated storms were considered, meaning those storms that existed without any significant interaction with other storms. Storms or other echoes along the rear-flank of supercells often contaminated the reflectivity field and could of masked the occurrence of a DRC.

As might be expected, this study does not offer itself as representative of all supercells in all months, seasons, or geographies. Many storms were not considered due to contamination in the reflectivity field by other cells, falling outside of the 100 km range limit, or not having echo appendages. Further, other storms could not be considered due to missing WSR-88D data. This work should be treated as a characterization of DRCs within *isolated supercells with persistent rear-flank hook echo appendages*.

c. Determination and analysis of DRCs

Rasmussen et al. (2006) set forth an objective way to determine which echoes within the rear-flank appendage of a supercell are DRCs. To qualify as a DRC, an echo must first be pendant from the echo overhang in the right-rear flank of the supercell. Once the DRC reaches the lowest elevation tilt, it must be associated with an isolated core of four dB greater than the highest value along the path of the appendage leading to the core. The purpose of these requirements is to ensure that the echo is isolated and not just a typical appendage.

Volume scans that met the surface requirements for a DRC were marked for objective analysis. Additional scans were considered 10 to 15 min prior to detect the descent of the DRC. Data were objectively analyzed using a Barnes (1964) weighting function to smooth the data in a fashion similar to Rasmussen et al. (2006).

Tornado intensities, times, and locations were taken from the NCDC Storm Event Database. DRCs were marked tornadic if they reached the base tilt of radar data within 10 min prior to five min after tornado formation. A less stringent time period of 30 min prior to 15 min after also was tested. The latter time period offers a better comparison to DRC studied in Rasmussen et al. (2006). No effort was taken to correct reports in cases where tornado times appeared erroneous, although the 15 and 30 min time window should mitigate some of the possibilities of falsely associating a DRC with no tornado.

3. Results

Four months of data from 12 WSR-88D radars contained 64 isolated supercells with persistent appendages. Of these, 33 (52 percent) were tornadic, while the remaining 31 (48 percent) did not produce tornadoes. Despite the large percentage of tornadic supercells within this study, the reader should not be alarmed. Considering the sample is constrained to isolated supercells with persistent appendages, it is not hard to fathom that these storms would be more likely to produce tornadoes; appendages are widely believed to be caused by the advection of hydrometeors around low-level mesocyclones and tornadocyclones (Fujita 1958; Browning 1965; Brandes 1977). Nearly 60 percent (39 of 64) of the storms produced at least one DRC during their analyzable lifetime.

A breakdown of isolated supercells into groups of what phenomena they produced is shown in Fig. 1. The most common type was those that had both DRCs and tornadoes (36 percent). The least common was storms that produced tornadoes with no DRCs (16 percent). Non-tornadic supercells were split nearly in half between those that did and did not produce DRCs. From the storms in this study, 89 tornadoes occurred. These broke down into the classic distribution of exponentially more numbers of weaker tornadoes. Seventy-one DRCs were recorded from the 39 DRC

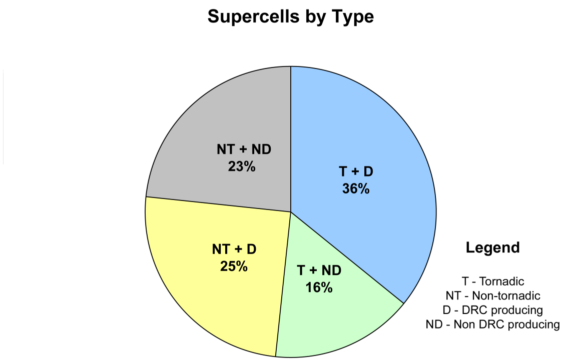

Fig. 1. Supercells categorized by the type of phenomena they produced.

producing supercells. Twenty of these 39 (51 percent) produced one DRC, while 18 of the remaining 19 storms had two to three DRCs reported. Two or three DRCs were recorded with 18 of those 19; one outlier produced 10 DRCs (as well as 13 tornadoes) over a span of 7 hours across the domains of two radars.

By determining the time in between DRC occurrences and reported touchdowns of tornadoes, associations were determined between the two events. For a time period of 10 min prior to 5 min after a tornado report, 21 of 71 (30 percent) of DRCs were associated with tornadoes. This consisted of 24 percent of the total number of tornadoes within the study. Increasing the time period to 30 min prior to 15min after drastically changed the statistics. With this time span, 29 of 71 (41 percent) of DRCs occurred temporally near reports of tornadoes, while 42 of 89 (47 percent) of tornadoes were included. Multiple tornadoes fell within time periods for several of the DRCs which accounted for the increased number of tornadoes.

Additional percentages were calculated for storms that produced multiple DRCs and/or multiple tornadoes. Of the 19 supercells that had multiple tornadoes, 68 percent (13 of 19) produced DRCs. Nearly the same percentage of supercells that produced multiple DRCs compared to a single DRC were tornadic (58 percent compared to 59 percent).

4. Discussion

Similar to Rasmussen et al. (2006), this study found that DRCs occurred in both tornadic and non-tornadic supercells. A substantial amount of supercells (41 percent) did not produce DRCs, although the smallest minority (16 percent) of the study was tornadic, non-DRC producing supercells. Within a small sample of storms, Rasmussen et al. (2006) found DRCs descended prior to every tornado. Even though this study has shown this is not always the case, 30 percent (41 percent) of DRCs descended within 10 (30) min prior to 5 (15) min after reported tornado onset. (Note that WSR-88D data are available at any level approximately every 5 min). While this may seem insignificant, the occurrence of the DRC was a better indicator for tornadogenesis than the hook echo or other appendages; only 19 percent of 950 hook echoes at any given time, as defined by Forbes (1981), were associated with a tornado. How these two numbers relate is questionable; while the hook echo is determined at a single point in time, the DRC descends over a time period of 10 to 15 min. Despite this issue, supercells with a persistent appendage and DRCs are a better indicator for tornadoes than the hook echo alone. Forecasters should have heightened awareness when both phenomena are observed within an isolated supercell. The reader is reminded, however, that DRCs should not be used as a condition necessary for tornado onset; 53 percent of tornadoes occurred outside of 30 min before to 15 min after reported tornado onset.

Although WSR-88D data quality issues such as range folding and noise precluded a thorough study of velocity data surrounding the DRC, an effort to subjectively analyze this data was made. The magnitude of outflow in the rear-flank of the supercell for DRCs within 60 km (where beam height is approximately one km AGL) was analyzed prior to and after descent of DRCs. Whereas some DRCs did not appear to influence single Doppler velocities at the base scan, the majority (65 percent) did. This included many DRCs that were not associated with tornadoes. When this outflow was enhanced, outflow representative of the RFD was already present; the DRCs occurred after the initial development of the RFD.

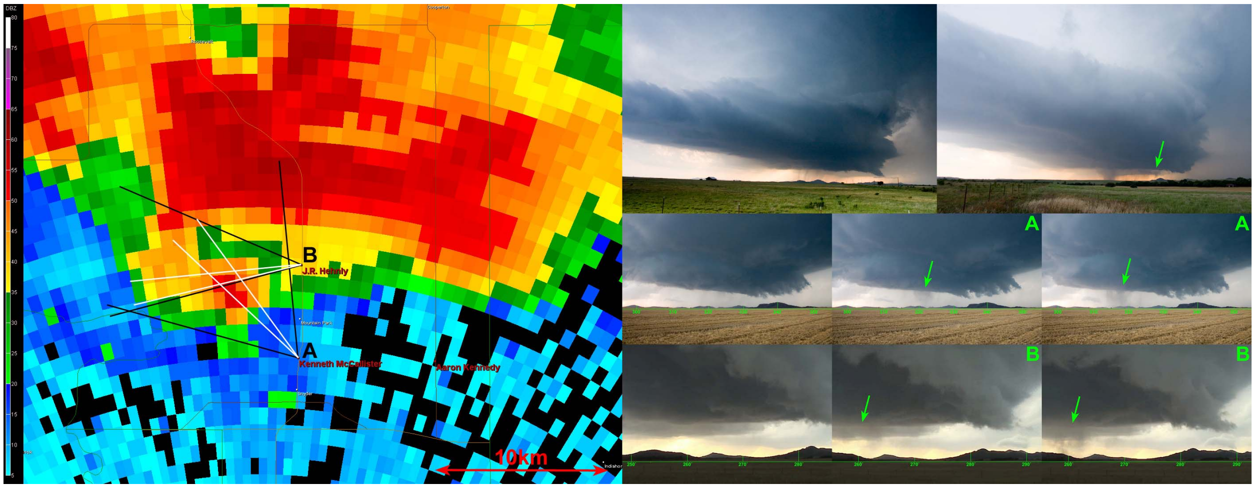

Fig. 2. Locations of the storm observers for photographs and video captured around 0018 UTC on 6 June 2005. For the reader's aid, green arrows point out the DRC while true headings are displayed for the bottom two panels.

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5. Visual Observation of a DRC

During 0000-0100 UTC of 6 June 2005, an isolated supercell near Snyder, OK produced a descending reflectivity core (DRC) followed by two tornadoes. Several storm spotters including one of the authors of this paper observed this storm in detail with still photos and video. Although the DRC has been well documented in radar data by Rasmussen et al. (2006), visual evidence of this feature has thus far been nonexistent.

a. Lifecycle and radar observation of the supercell

The supercell of interest had a relatively brief life of only a few hours. The storm initiated at approximately 2300 UTC on 5 June, along the flanking line of an already present thunderstorm. By 0000 UTC, the storm quickly took on the visual characteristics of a classic supercell: a large rain-free updraft base, removed forward-flank precipitation core, and developing mid level inflow tail. The storm had already produced hail greater than 7.5 cm in diameter near Roosevelt, OK. Within 30 min, the storm became tornadic; it produced a brief F0 tornado at 0025 UTC with no discernable damage path, and a stronger F1 tornado at 0036 UTC. After this mesocyclone occluded (Brandes 1978), the supercell failed to produce further tornadoes. Rapid development of convection along the rear-flank and surging outflow ended the tornadic phase of the storm by 0100 UTC.

As the 5 June supercell transitioned to a tornadic state, its reflectivity structure evolved rapidly. At 0008 UTC, the supercell had a large overhang and weak echo region. Over the span of 10 min, the overhang of reflectivity quickly grew in volume with a DRC descending to the surface by 0018 UTC. Even prior to the DRC reaching the lowest tilt, a weak reflectivity hook echo was present. Once the DRC reached the surface, reflectivity in the appendage increased by 5 to 15 dB. Based on radar data, the DRC was approximately 1-2 km in diameter at a height of 0.4km AGL.

b. Photographic documentation of the DRC

Numerous storm observers, including the author, inadvertently documented the descent of this DRC. Positions of these storm-spotters were obtained after the fact via a GPS field survey. Accuracy of this data is limited by the resolution of the GPS and the ability to locate the observers' exact locations. GPS data is estimated to be within a dozen meters of accuracy. With the large quantity of identifiable objects within the pictures, errors in location are believed to be negligible.

Prior to the descent of the DRC, the hook echo was visually manifested with rain curtains advecting around the periphery of the low-level mesocyclone at 0014 UTC. Five min later, these rain bands were accompanied by additional curtains of rain to the west-southwest of the wall cloud. Note that from the author's position, the dense column of precipitation is due to looking down the "neck" of the hook echo; the DRC actually occurred north of this region.

Evidence of descending rain curtains within the RFD extends from photographs and video taken by Mr. Kenneth McCallister and Mr. J.R. Hehnly, undergraduate students from the School of Meteorology at the University of Oklahoma. In a rapid sequence of photographs, Mr. McCallister documented rain curtains suddenly descending over the span of 50 seconds from 0017 to 0018 UTC. Given an LCL of 1000m AGL from the OUN sounding, this downdraft was estimated to descend at approximately 20 m s^{-1}. Video taken by Mr. Hehnly documented the same descending rain curtains as seen by Mr. McCallister as well as the descent of the cloud base. Sharing the scene of the storm were numerous peaks of the western Wichita Mountains, which added to the serendipitous nature of the day; these peaks would allow for an easy photogrammetric analysis of the DRC.

With aid of United States Geographical Survey topographic maps and GPS information, a simple photogrammetric survey was completed for select frames from Mr. Hehnly and Mr. McCallister's footage. From this analysis, field of views and true headings for frames A and B in Fig. 2 were obtained. It is easily seen that these rain curtains were associated with the DRC. With elementary trigonometry, the visual width of the DRC was estimated. The DRC was 1.1km and 0.6km wide from Mr. McCallister and Mr. Hehnly's viewpoints, respectively.

c. Discussion

In this case, the DRC was associated with a narrow column of rain curtains which descended from the cloud base. While the hook echo was originally associated with wrapping rain curtains, it was later enhanced by the descent of the DRC. What remains unknown is whether this is common amongst hook echoes. In the past, the hook echo has been widely attributed to simple advection and descent of hydrometeors around the low-level mesocyclone (Fujita 1958a; Browning 1965; Brandes 1977a). The observation of the DRC within this paper may be evidence of a more complicated chain of events. Even more intriguing, this evolution occurred seven minutes prior to the storm becoming tornadic. This example is far from an isolated case as discussed in section 3.

Numerous field-projects have been conducted on supercells, but as far as the authors know, such an observation of rapid, vertically descending rain curtains in the hook echo have not been documented in literature (although a similar feature is apparent in many photographs of supercell rear flank regions). The reader may wonder why these projects have failed to observe the DRC. While we don't have the answer to this question, some insight can be gained from the photos within this paper. From the author's perspective, the DRC was not visible at the time it occurred. Unless you were near the DRC, these descending rain curtains would be overlooked in real-time because of lack of contrast or other rain curtains obscuring the view. Further more, the small size of the DRC (on the order of a kilometer) and quick descent made it easy to overlook. The last aspect that may have hindered the detection of the DRC is its location removed from the rotating wall cloud. Naturally, most storm-observers would be paying closer attention to this critical feature of the supercell.

6. Summary

A characterization of DRCs for a large sample of isolated supercells with persistent rear-flank appendages was completed. In summary, 39 (61 percent) of the 64 supercells produced DRCs with 59 percent of those storms being tornadic. Only 16 percent of the supercells were tornadic and non DRC producing. Forty-one percent of DRCs descended within 10 (30) min prior to 5 (15) min after reported tornado onset. Compared to the hook echo, the DRC was a better indicator for tornadogenesis, however, 53 percent of tornadoes were not associated with DRCs.

For DRCs within 60km of a WSR-88D, 65 percent were associated with an increase in outflow in the rear-flank of the supercell. In many cases, this was observed even for non-tornadic DRCs. Some DRCs descended in a variety of ways including nearly vertical, learning towards the front flank, and trailing towards the rear flank. The significance of this is unknown, although it is possible one type may be favored for tornadoes.

During the course of this work, the author and several storm observers documented the first visual observation of a DRC on 6 June

2005. This phenomenon was associated with a small core of precipitation which descended from a region southwest of the wall cloud after wrapping rain curtains formed a hook echo. The DRC descended at approximately 20 m s^{-1} and was 0.6 to 1.1 km in width. After descent of this DRC, reflectivity increased by 5-15 dB.

Many questions pertaining to DRCs remain unanswered. The microphysical makeup of these reflectivity protuberances is unknown, although research using dual-polarimetric radar is currently underway. What the DRC means dynamically is also undetermined. Can the DRC instigate tornadogenesis or is it a mere association? How does the location (classification) of the DRC impact supercell dynamics? It is hoped these questions may be answered with future work involving dual-Doppler analysis of supercells as well as idealized numerical simulations. An additional path of research involves the use of mobile Doppler radar platforms such as the DOWs (Wurman et al. 1997) and SMART-Rs (Biggerstaff et al. 2005). Such radars offer superior resolution to the WSR-88D network and could answer the question of whether we can or cannot see some DRCs due to limitations in the WSR-88D network.

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REFERENCES

Barnes, S. L., 1964: A technique for maximizing details in numerical weather map analysis. *J. Applied Meteor.,* **3**, 396-409.

Brandes, E. A., 1977: Flow in a severe thunderstorm observed by dual-Doppler radar. *Mon. Wea. Rev.,* **105,** 113–120.

——, 1978: Mesocyclone evolution and tornadogenesis: Some observations. *Mon. Wea. Rev.,* **106,** 995–1011.

Biggerstaff M. I., L. J. Wicker, J. Guynes, C. Ziegler, J. M. Straka, E. N. Rasmussen, A. Doggett IV, L. D. Carey, J. L. Schroeder, and C. Weiss, 2005: The Shared Mobile Atmospheric Research and Teaching Radar: A Collaboration to Enhance Research and Teaching**.** *Bull. Amer. Meteor. Soc.*, **86**, 1263–1274.

Browning, K. A., and R. J. Donaldson, 1965: Some inferences about the updraft within a severe local storm. *J. Atmos. Sci.,* **22**, 669-677.

Brown R.A., B.A. Flickinger, E. Forren., D.M. Schultz, D. Sirmans, P.L. Spencer, V.T. Wood, and C.L. Ziegler, 2005: Improved Detection of Severe Storms Using Experimental Fine-Resolution WSR-88D Measurements. *Weather and Forecasting,* **20**, 3-14.

Forbes, G. S., 1978: Three scales of motions associated with tornadoes. U. S. Nuclear Regulatory Commission, NUREG/CR-0363, 359 pp., [NTIS PB288291.]

_____, 1981: On the reliability of hook echoes as tornado indicators. *Mon. Wea. Rev.,* **109,** 1457-1466.

Fujita, T. T., 1958: Mesoanalysis of the Illinois tornadoes of 9 April 1953. *J. Meteor.,* **15,** 288–296.

Hart, J.A., 1993: SVRPLOT: A new method of assessing and manipulating the NSSFC Severe Weather data base. Preprints, 15th Conf. on Severe Local Storms, Baltimore, MD, Amer. Meteor. Soc.,40–41.

Markowski, P. M., 2001: Hook echoes and rear flank downdrafts: a review. *Mon. Wea. Rev.,* **130,** 852-876.

Rasmussen, E. N., J. M. Straka, M.S. Gilmore, and R. Davies-Jones, 2006: A preliminary survey of rear-flank descending reflectivity cores in supercell storms. Submitted to *Weather and Forecasting (in press)*

Wurman, J., J.M. Straka, E.N. Rasmussen, M. Randell, A. Zahrai, 1997: A portable pencil-beam pulsed Doppler Radar. J. Atmos. Oceanic Tech., **14**, 1502-1512.