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A Visual Observation of the 6 June 2005 Descending Reflectivity Core

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ABSTRACT

A visual observation of a descending reflectivity core (DRC) is presented in tandem with radar data from the Frederick, OK WSR-88D for a supercell storm that occurred on 6 June 2005. The DRC appeared as a dense column of precipitation to the right of the main core, west-southwest of the wall cloud. Through the use of stereo photogrammetric techniques, it is shown that these rain elements corresponded with a local maximum of reflectivity within the supercell echo appendage.

1. Introduction

From 0000-0100 UTC on 6 June 2005, an isolated supercell near Snyder, OK produced a descending reflectivity core (DRC) that was followed by two tornadoes. Several storm spotters, including one of the authors of this paper (AK), 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) and Kennedy et al. (2006), a comparison to visual evidence thus far has been non existent.

The DRC is manifest on radar by a reflectivity protuberance that descends from the echo overhang. Falling into the right-rear flank of the supercell, it either can create an echo appendage or intensify reflectivity within a pre-existing one. In single-Doppler velocity data, the DRC often is associated with an enhanced region of rear-to-front low-level flow. Because the rear-to-front flow is spatially isolated, this velocity signature can be straddled by a pair of counter-rotating vortices (Fig. 1). Considering the cyclonic vortex sometimes is associated temporally and spatially with tornadoes (Kennedy et al. 2006), the DRC could be related to the onset of tornadogenesis.

This paper is divided into five sections. In section two, the lifecycle of the supercell is described. Visual observations then are compared to radar data with the aid of Global Positioning System (GPS) data and topographic maps in section 3. A discussion of these observations is provided in section 4, while a brief summary of key points is outlined in section 5.

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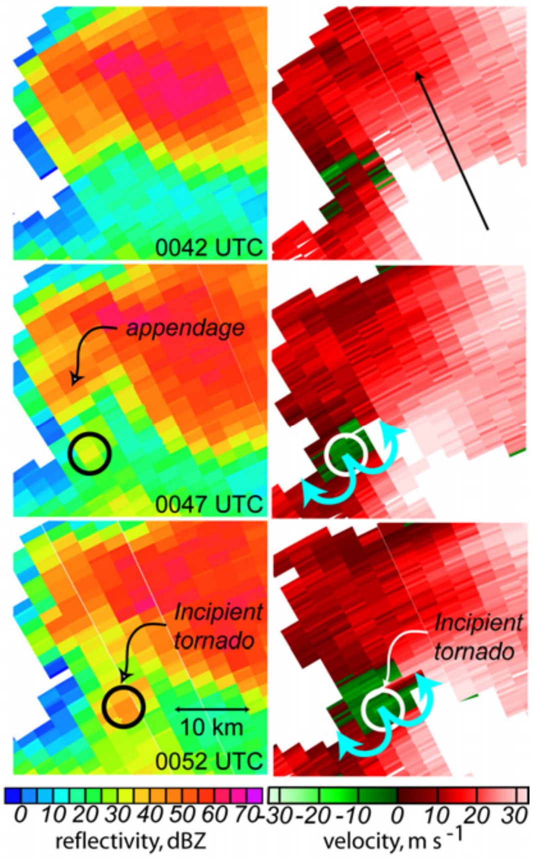

Figure 1: Example of a DRC with spatially isolated rear-to-front flow. The left-hand column contains 0.5º PPI reflectivity scans while the right-hand column displays ground-relative Doppler velocities. In the upper right panel, the black arrow orients the velocity data. Cyan arrows in the bottom two panels denote shear near the DRC. [Figure adapted from Rasmussen et al. (2006).]

2. Lifecycle of the supercell

The supercell of interest had a relatively brief life of only a few hours. The storm began at approximately 2300 UTC on 5 June along the flanking line of an existing thunderstorm in southwest Oklahoma. By 0000 UTC, the storm quickly took on some of the visual characteristics of a classic supercell: a large rain-free updraft base, forward-flank precipitation core, and developing midlevel inflow tail (Fig. 2). By this time, 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 that had no discernible damage path and a stronger F1 tornado at 0036 UTC. After this mesocyclone occluded (Brandes 1978), the supercell failed to produce any more tornadoes. Rapid development of convection along the rear flank and surging outflow ended the tornadic phase of the storm by 0100 UTC.

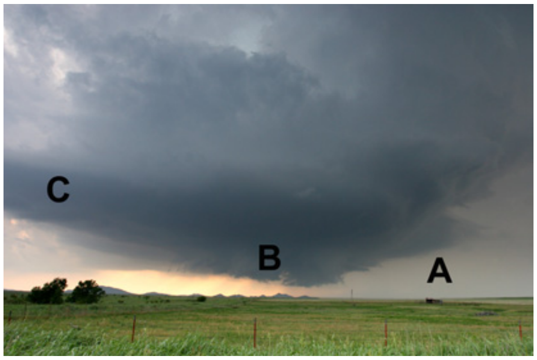

Figure. 2: Photograph of the supercell taken by the author at approximately 0000 UTC before the development of an appendage. The view is facing WNW. Note the removed forward flank precipitation core (A), large rain free base (B), and developing mid-level inflow tail (C).

As the 5 June supercell transitioned to a tornadic state, its reflectivity structure evolved rapidly. At 0008 UTC, the supercell had a region of higher reflectivity at 3.2 km AGL to the rear of a weak-echo region. Over the span of ten min, this protuberance of reflectivity quickly grew in volume with a DRC reaching the surface by 0018 UTC (Fig. 3). Even prior to the DRC reaching the lowest radar 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 0.4 km AGL. By the following volume scan (0023Z), reflectivity throughout the rear flank of the supercell filled in resulting in a large column extending from the surface to the overhang. In the following ten minutes and prior to the second tornado (which occurred near the velocity couplet visible in the last panel), this column of reflectivity substantially decreased in volume. Instead of the DRC, the most striking reflectivity feature at this time was the newly developed bounded weak echo region to the east.

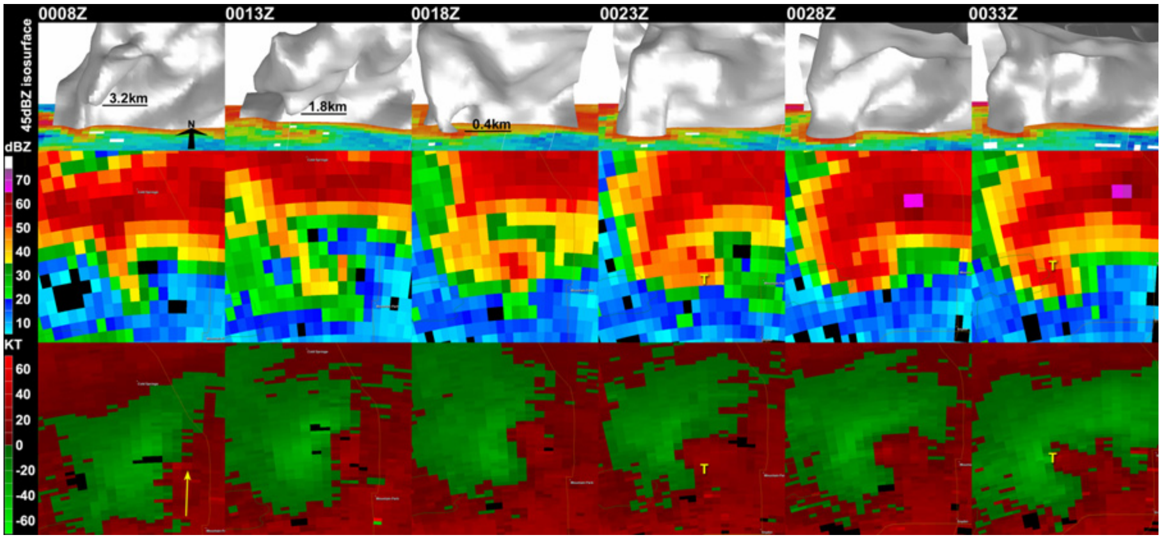

Figure 3: Top panel: time evolution of the 45 dBZ isosurface from 0008 to 0033 UTC. All views are looking due north. Heights given for the bottom of the DRC isosurface are AGL. Middle and bottom panel: corresponding 0.5° tilt reflectivity and storm relative velocity PPI scans from the Frederick, OK WSR-88D. The yellow arrow indicates the orientation of the velocity data.

3. Photographic documentation of the DRC

a. Photogrammetric analysis

Numerous storm observers, including AK, documented the descent of this DRC photographically. Their positions (location determination described later) relative to the DRC are shown in Fig. 4. Before descent of the DRC, the supercell echo appendage was manifest visually by visible precipitation elements that were being advected around the periphery of the low-level mesocyclone, as seen in Fig. 5 at 0015 UTC. Five minutes later, these elements were accompanied by a denser patch of precipitation to the WSW of the wall cloud. Note that from AK's position, the dense column of precipitation likely is due to looking down the "neck" of the hook echo; the DRC actually occurred north of this region. Evidence of descending precipitation elements within the RFD comes from photographs and video taken by Mr. Kenneth McCallister and Mr. J. R. Hehnly. In a rapid sequence of photographs, Mr. McCallister documented the visible elements suddenly descending from 0017 to 0018 UTC.

A simple photogrammetric analysis for the DRC was completed for Mr. McCallister's pictures and for select frames from Mr. Hehnly's footage. Camera locations were determined using perspective relationships between foreground and background features in the image, and have an uncertainty of about 1.5 m (see Rasmussen et al. 2003 for a comprehensive discussion of photogrammetry and error sources). Once camera sites were found, GPS receivers were used to determine geographic location to within 10 meters of accuracy. The camera sites were plotted on a panel of the United States Geological Survey's 7.5° x 7.5° quadrangle map through Geographic Information System (GIS) software. This map database offered the highest resolution of any USGS product, with 90% of horizontal points within 12.2 m (40 ft) of accuracy, and 90% of vertical points within one-half of a contour interval (1.5 m or 5 ft).

Camera orientation was determined as follows. Headings were found between camera and terrain features visible in the images by assuming terrain peaks were centered within the highest closed terrain contour level (Fig. 6). From this analysis, fields of view and orientation for frames A and B in Figs. 4 and 5 were calculated by a subjective linear fit to the terrain features. This analysis confirmed that these dense visible precipitation elements in the images were associated with the DRC. Furthermore, the visual width of the DRC was estimated to be 1.1 km and 0.6 km from Mr. McCallister and Mr. Hehnly's viewpoints, respectively.

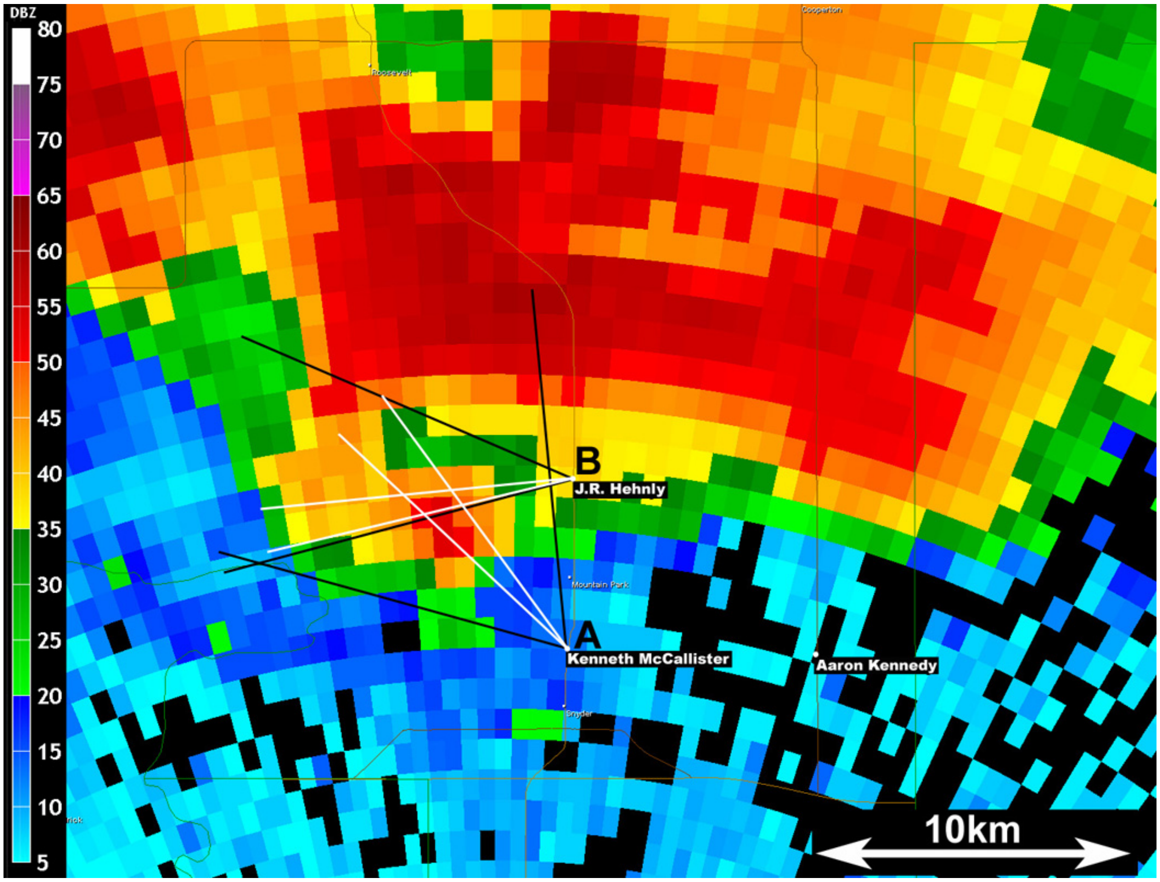

Figure 4: Locations of the storm observers who captured photographs and video presented in Fig. 5. At the time of the DRC, Mr. J. R. Hehnly was 4.4 km to the east-northeast, Mr. Kenneth McCallister was 5.6 km to the southeast, and the author was 13 km to the east-southeast of the DRC. Fields of view are depicted by black lines for frames A and B in Fig. 5. The white lines indicate the extent of the visually dense precipitation column within these respective frames.

b. Error analysis

As described above, image orientation was determined by using identifiable landmarks (mountain peaks) in the images. Considering the distance to mountains was several orders of magnitude larger than the GPS error, heading errors should be negligible for this error source. Assuming that the highest terrain feature in photographs could occur anywhere within the highest closed terrain contour level, it was possible to estimate the maximum expected error. The largest angle found between the presumed peak location and its associated closed contour was 0.5°. Taking the tangent of this angle and multiplying by the distance between the cameras and radar-depicted DRC resulted in a maximum horizontal displacement error of approximately 50 m. Image scaling was determined by estimating the ratio of image pixel separation to angular landmark separation for all available landmarks.

Additional information was available to check scaling errors. For McCallister's photos, a variety of information was available, owing to the digital format of his pictures. Parameters such as focus distance, camera body and lens type, focal length, and time were accessible within Exchangeable Image File Format (EXIF) data. In the case of these photographs, a digital single-lens reflex (DSLR) camera with 18–55 mm lens was used. Although the lens was designed to be rectilinear, it is well known that wide angle lenses frequently suffer from some barrel distortion. Prior to completion of the analysis, these photographs were corrected using an off-the-shelf software package that removes barrel distortion and pincushion (a distortion causing lines at the image edge to curve inwards), and corrects for a skewed horizon.

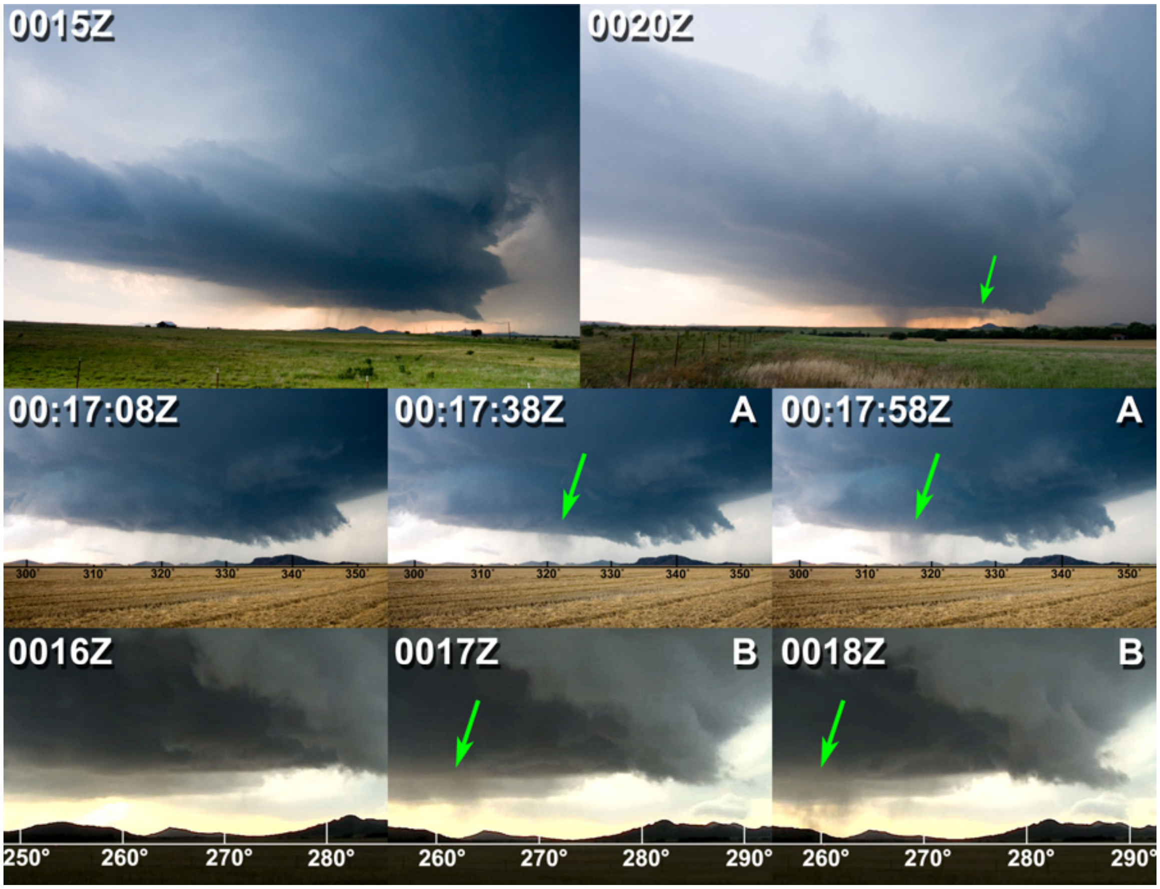

Figure 5: Visual observations of the DRC: Top panel: photographs taken by the author at 0015 UTC (left) and 0020 UTC (right). Middle panel: photographs by Mr. McCallister between 0017 UTC (left) and 0018 UTC (right). Bottom panel: screenshots from video by Mr. Hehnly from 0016 UTC (left) to 0018 UTC (right). Green arrows point out the DRC and true headings are displayed for the bottom two panels. Note the rapid descent precipitation elements from the cloud base. In the bottom panel, it appears as if the cloud base descended prior to the descent of the DRC. Locations of the photographers are provided in Fig. 4.

Such a correction has its drawbacks, such as near-field objects appearing distorted. Fortunately, all objects of interest could be considered to be in the far field. The benefit of having an effectively rectilinear lens is that objects within the field of view are connected by straight lines through the lens focal point to objects in the image (projectivity). Therefore, angular displacements are represented by the same distance (pixels) along horizontal and vertical lines.

By comparing image scaling and orientation estimated from the headings in Fig. 5 with the field of view (FOV) calculated from known optical parameters for Mr. McCallister's camera, orientation and scaling errors were estimated. Given the camera's sensor size of 22.7 x 15.1 mm and a focal length of 18 mm, FOV for Mr. McCallister's images was 64.47°. Using this image angular width, and a digital image size of 3072 x 2048 pixels, one degree in angular displacement corresponded with an image displacement of approximately 48 pixels. In examining the difference between landmark headings estimated from the scaled image to headings estimated from topographic contours, and utilizing the nominal image scaling found through the camera parameters, the maximum error was 0.35°. As a result, image orientation is known to within 0.5°, an accuracy made possible by the number of mountain peaks contained within the images. Unfortunately, this analysis could not be performed on Mr. Hehnly's footage because the focal length and other properties of his camcorder were not recorded.

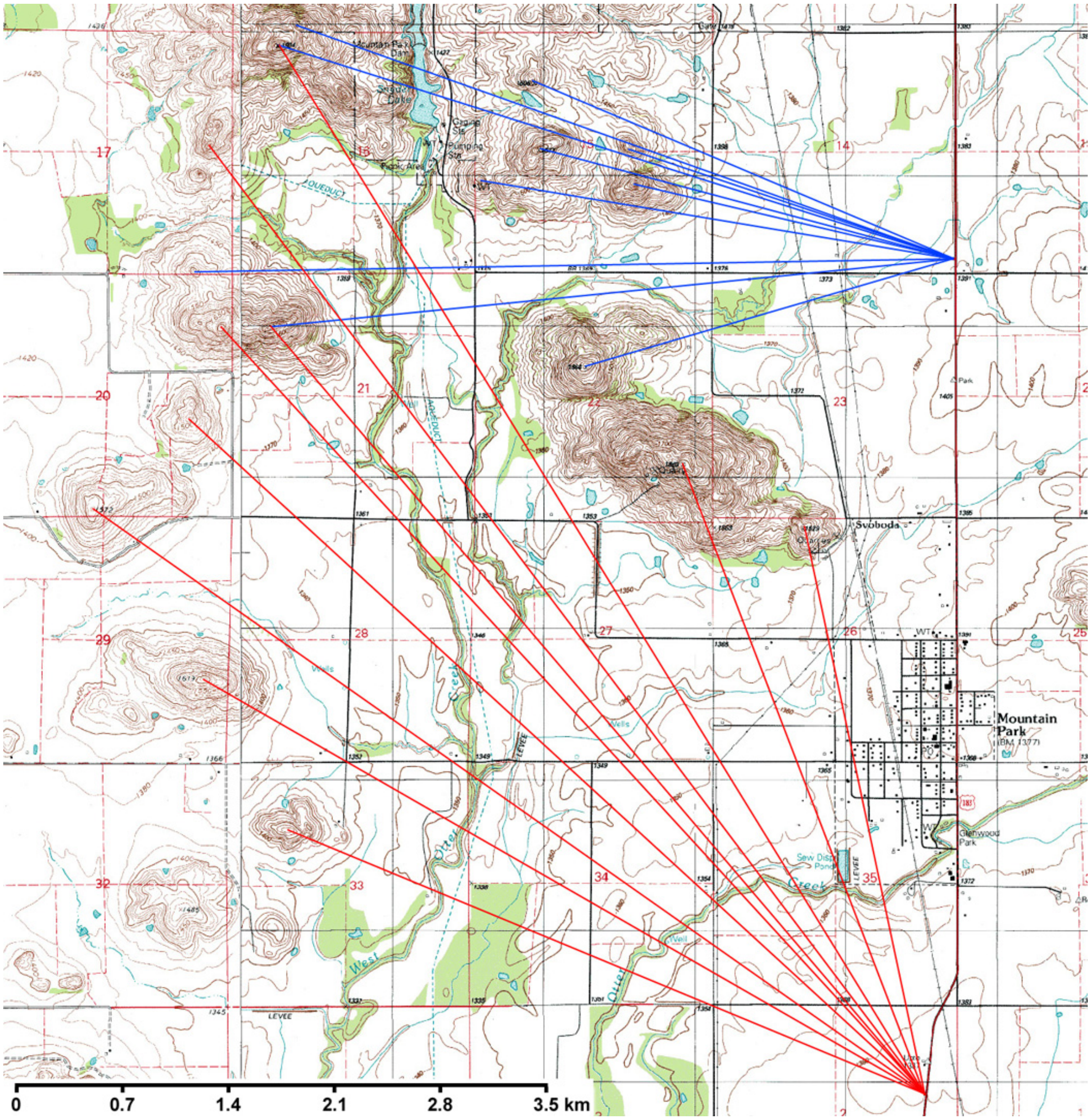

Figure 6: USGS 7.5 x 7.5° topographic map of the Mountain Park, OK region with headings overlaid from observer locations to terrain features.

c. Estimation of the DRC descent speed

Time stamps from Mr. McCallister's digital files enabled a calculation of precipitation fall speed associated with the DRC. Visible precipitation elements that constitute the DRC ("rain curtains" in the vernacular) took 50 sec to descend from cloud base to the surface. Lifted condensation level (LCL) height may be estimated either by proximity sounding or from the photogrammetric analysis. Correcting the Norman, OK (OUN) sounding for elevation differences, the LCL was determined to be ~950 m AGL. Several cloud base heights (possibly indicating local LCL variations) were evident within the photographs, however, and photogrammetric analysis suggests the DRC descent region had a cloud base of approximately 775 m. With an uncertainty of 0.5° in orientation, the cloud base height had an uncertainty of approximately ± 50 m. Given the latter height values, precipitation elements constituting the bottom of the DRC descended at between 14.5–16.5 m s^{-1}. This implies a downdraft of at least 7.5–4.5 m s^{-1}, given the maximum terminal velocity (large raindrops; Beard 1976) of 9–10 m s^{-1}. Video taken by Mr. Hehnly documented the same descending precipitation elements as seen by Mr. McCallister, as well as descent of the cloud base in that area immediately prior.

4. Discussion

In this case, the DRC was associated with a narrow column of visible precipitation that descended from the cloud base. While the echo appendage originally was associated with precipitation advected around the rear of the mesocyclone, it was enhanced later by the descent of the DRC.

What remains unknown is whether this is common in rear-flank supercell echo appendages. In the past, the hook echo has been widely attributed to simple advection and descent of hydrometeors around the low-level mesocyclone (Fujita 1958; Browning 1965; Brandes 1977). The observation of the DRC within this paper may be evidence of a more complicated chain of events. Even more intriguing, the DRC descent into the subcloud layer occurred seven minutes prior to the storm becoming tornadic. This example is far from an isolated case-- within a large sample of storms, 41% of DRCs occurred within a temporal window from 30 min prior to 15 min after reported tornado onset (Kennedy et al. 2006).

Numerous field projects have been conducted on supercells, but to our knowledge, such rapid, vertically descending "rain curtains" in the hook echo have not been documented formally 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. Although there is not a definitive 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 that it occurred. Depending on perspective and distance, the descending precipitation in the DRC could be overlooked in real-time because of a lack of contrast or other precipitation obscuring the view. Moreover, the small size of this DRC (~1 km) and its quick descent made it easy to overlook. Finally, the location of the DRC can be relatively distant from the rotating wall cloud. Naturally, most storm observers could be paying closer attention to a wall cloud or area of intense rotation and may not observe the DRC.

5. Summary

Thanks in part to several storm observers, the first documentation of a DRC with both radar data and pictorial evidence is presented. In this case, the DRC was seen as a descending column of precipitation approximately 1.1 km in diameter, embedded in a downdraft determined to be of at least 4.5–7.5 $\mathrm{m\,s^{-1}}$. This DRC developed to the west-southwest of the wall cloud and could only be observed from nearby locations. It occurred just prior to the storm's tornadic phase; however, the exact relationship between DRCs and tornadogenesis is still unknown.

It is hoped that this paper can serve as an example of what is possible with well documented images and video of storm events. With dozens of storm observers on any given storm during the severe weather season, the possibility exists for even more detailed photogrammetric analyses of supercells. From these analyses, it will be possible to map fully the extent of cloud and precipitation elements on radar data. Such datasets have limitless potential for operational and research meteorologists alike.

Acknowledgements

Support for this research was provided by the National Science Foundation through Grant ATM-0340693. The authors would like to acknowledge storm observers J.R. Hehnly and Kenneth McCallister for their kind contribution of media. Without their assistance, this paper would not have been possible. Additional thanks are extended to Dr. Mark Askelson for his helpful comments on this manuscript. The reviewers of this paper for *E. Journal Severe Storms Meteor.* were Charles Doswell III, Jim LaDue, and Brian Smith; their comments led to a substantially revised, focused, and improved presentation. We thank them for their time and collegial approach to the review process.

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Rasmussen, E. N., J. M. Straka, M. S. Gilmore, and R. Davies-Jones, 2006: A survey of the occurrence of rear-flank descending reflectivity cores in a sample of supercells. *Wea. Forecasting*, **21**, 923-938.

REVIEWER COMMENTS

[Authors' responses in *blue italics*.]

General comments:

We would like to thank everyone for the extensive reviews. It is apparent that a significant portion of the comments are directed towards figures and discussion about the mesoscale environment. While these comments are well taken, the focus of the paper pertains to the visual observation of the DRC. The comments make it clear that the mesoscale discussion is distracting to the reader. Considering we know little about how environmental variables may influence whether a storm produces DRCs, we feel that in retrospect, this portion of the paper is not very relevant to the main topic. In current form, we have omitted this discussion and associated figures with permission of the reviewers. Instead, we have expanded the paper focusing on the radar evolution of the supercell and methodology of the photogrammetric analysis. A separate subsection has been created detailing an error analysis. Responses to specific comments are listed below.

REVIEWER A (Brian E. Smith):

Initial Review:

Recommendation: Accept with Major Revisions

Substantive comments

[Former Fig. 1] This map is pretty simple. It would probably be better to have the map analyzed for at least pressure and dewpoint fields to give the reader a better feel for the mesoscale environment.

[Mesoscale environment] You may want to expound on this in more detail. Where was this disturbance at? Also, it might be good to show a map or satellite imagery indicating the disturbance.

[Former Fig. 2] Besides the Skew-T shown, a map analysis of CAPE would be helpful in visualizing the situation.

Omitted, see above.

[Current Fig. 1] Where were the tornadoes in relation to the radar images shown? It might be good to include this in the reflectivity graphic.

Our first reaction to this query was to put the tornado locations in the graphic. After contemplating this, we decided to remove them and slightly modify the text. The problems with showing tornado locations with respect to radar depictions are several. First, there is no way to ascertain tornado location at the particular time of the radar sweep because of the significant uncertainty in time reporting. There is also no way to account for vortex tilt below the sweep level. What these questions really demand is a good photogrammetric analysis of the tornadoes with respect to the radar data, using time-stamped data sources.

The fact that our story is not about the relationship of tornadoes with the DRC, but instead about the visual character of the DRC, weighs in favor of not including details that cannot be known with much precision. Perhaps more importantly, much research remains to be done concerning the relationship of the DRC to tornadoes. Based on one case studied in detail (Dimmitt), it is clear that the tornado formed in the forward left portion of the DRC precipitation (it sure didn't look like it was in rain, but the data are indisputable!). With time, the DRC continued to advance with the Dimmitt storm, while the tornado moved leftward and more slowly, giving the appearance of being shed by the DRC and left behind. This sort of information is clearly valuable from a warning perspective, but this article is not the place to explore, or even comment on, the tornado location with respect to the DRC.

[Current Fig. 3] You might want to include some directions (azimuth angles perhaps) in the 3-D visualization of the DRC. What height or elevation is the DRC originating at?

I have substantially modified the figure so all views are looking due north. I have also labeled the AGL height to the nearest tenth of a kilometer for the DRC.

[Section 3] Did the observer not know their exact locations? You said the GPS is accurate within 10 meters (33 feet). Did the photographers not have a GPS with them when photographing? Did you use the photographs that were taken and use photogrammetry to determine the locations?

While GPS locations were given by the two observers, one of these coordinates was suspect. The physical location given did not match with the location in GIS software (comparing to county road maps). I decided to double-check these locations by doing a follow-up ground survey. I then compared GPS readings to the county road and topographic maps. I found the observer locations by comparing items in the photographs to my position. Considering the numerous terrain features at various distances, this was quite easy. Fences and trees in the foreground narrowed down these distances even further.

[Fig. 5] The photos would better show the possible DRC by increasing the contrast of the photos. Also, the azimuthal markings are unreadable... The font for the azimuthal markings needs to be larger.

The figure has been updated to add timestamps and improve clarity of the headings. I will admit that the contrast looks perfectly fine on my monitor. Perhaps a negative of an electronic journal is the wide variety of equipment people will use to view the document. Without calibration, monitors can vary substantially in both color representation and contrast.

We considered adding reflectivity isopleths on top of the observer's pictures, however, this leads to the issue of plotting a 2D isopleth onto a 3D structure. For the two observers closest to the DRC, the frame of view is small enough that there would be few data points to isopleth. Taking into account only one tilt was available below cloud base, we felt this wouldn't add substantially to paper.

REVIEWER B (Charles A. Doswell III):

Initial Review:

Recommendation: Accept with Major Revisions

Substantive comments

1. p.1, 2nd para. "In single-Doppler velocity data, the DRC is often associated with an enhanced region of rear-to-front, low-level flow." This description seems rather nebulous. It would be best to show this with a figure – either a schematic or an example shown from a real case. I think I know what the authors are trying to describe but this verbiage alone is not getting the job done.

An adapted figure from Rasmussen et al. (2006) has been included to go along with the narrative.

2. p.2, [former] Fig. 1. This figure is a good illustration of why Fred Sanders and I advocated drawing isotherms and isodrosotherms on surface charts in our 1995 BAMS paper. The insertion of a warm front offers little useful information in comparison to seeing the analyzed structure of the temperature and dewpoint temperature fields. I'm including a .ppt file [not shown] with my crude attempt at doing so, which I believe offers more insight to the reader than this vague description of the fields. Furthermore, the warm front doesn't look very much like a warm front to me. Rather, I see thermal boundaries elsewhere (noted in black on the figure).

See below.

3. [In what was…] p.3, 1st para. "In response to these forcings, an isolated supercell developed …" What do the authors mean by "forcings"? This is a pet peeve of mine as the word "forcing" is often used carelessly and vaguely in descriptions of the synoptic situation. There is no "convergence force," of course.

Point taken, forcing is indeed a bad term to use. What we meant was that either synoptic scale ascent from the disturbance or convergence along the boundary could have caused convection. As mentioned in the general comments, the inclusion of a brief mesoscale analysis was a mistake in retrospect. This was more of an afterthought to the paper, and does not support or relate to the focus of the paper. This paper's intention is not to be a full-fledged case study, but a look at a unique visual/radar structure that occurred during the lifetime of the storm.

4. p.4. I'd like to see more regarding the photogrammetric analysis. Perhaps a figure or two and some details about the calculations, including an error analysis, would add credibility to the results.

With the omission of the mesoscale environment material, we have expanded the paper to include additional details on the photogrammetric analysis. Two additional figures have been added. The first figure displays the topographic map and terrain features used. The second figure helps demonstrate an error analysis technique within this new subsection. Thanks to the large number of identifiable terrain features within the pictures, the photogrammetric analysis was quite accurate with errors of 0.5˚ or less in headings and a horizontal displacement of +/- 50 m in DRC location.

Second Review:

Recommendation: Accept with Minor Revisions

General Remarks:

Overall, this is much improved manuscript. Apart from a number of minor "editorial" suggestions, I believe the paper is now ready for publication. I'm including several of the minor changes I have to offer, but the manuscript should be given a very careful reading to find grammatical and punctuation errors, as I could have missed some. I have no need to see the revised text, unless major changes are necessitated by responses to another reviewer.

Suggestions:

The terminology "descending reflectivity core" is somewhat ambiguous, as noted by the other reviewers. It might be too late to change this, given that the authors have published papers elsewhere using this term. The term is indeed descriptive of what is being observed, but convective storms of all sorts produce "descending reflectivity cores" all the time. If the authors wish the term to apply exclusively to some portion of supercell storms only, I believe it needs some modification. As it stands, such a term carries with it the potential for problems when describing descending reflectivity cores in other contexts. I hope the authors will give some serious consideration to revising this term, or at least addressing the current ambiguity of the term as used. Creating new terminology is always a potential issue.

[Minor comments omitted…]

REVIEWER C (James G. LaDue):

Initial Review:

Recommendation: Accept with Minor Revisions

Short synopsis:

This paper documents a field observation of a Descending Reflectivity Core (DRC) into a hook echo region of a supercell in southwest Oklahoma of 05 June 2005. The authors associate the descent of relatively high reflectivities observed by WSR-88D to that visually observed by chasers from multiple viewpoints. The authors then supplied evidence that the descent rate of the visual part of the DRC exceeding that expected by the terminal velocity of large rain drops inferring an accompanying downdraft. A companion paper in press to *Weather and Forecasting* by the authors suggests a relatively high percentage of tornadic supercells are accompanied by DRCs just before tornadogenesis.

I like the paper and accept it after minor revisions. I'm also impressed that there is good observational (radar and visual) evidence of a DRC into a hook echo. In order to understand the relationship between this DRC and downdraft a little better, I make some comments below.

Major comments:

There are many references to descending reflectivity cores in literature associated with downbursts. Most storms have descending reflectivity cores. Even most supercells would have descending reflectivity cores in the main core region. Should some distinction be made of DRCs into the hook echo region of a supercell from DRCs in other parts of a supercell?

While there are other descending reflectivity cores, we are unaware of other instances where they have simply been stated as DRCs. With Rasmussen et al. (2006) now published in Weather and Forecasting*, this issue should be clarified.*

The type of DRC implied by the authors differs to the implications of a DRC with respect to microbursts (e.g., Atkins and Wakimoto, 1991). I would almost suggest that perhaps this type of DRC be given a more specific name should it be referred to without the overall context of the situation.

The rear-flank DRC often can take on microburst like appearances in radar data. Some DRCs (or maybe even a majority) may even appear as small microbursts. Time will tell as more observations come in.

I would've benefited with more description in how the authors estimated vertical velocity. What part of the DRC are they tracking? I have other detailed comments about the LCL height. I expect this is the main point of this case in that the DRC is occupied by downdraft.

In their discussion, they describe the DRC as a narrow column of rain curtains. However, they estimate vertical velocities within the DRC exceeding that of estimated terminal fall speed of rain drops. Would there be situations where descending precipitation may be forced downward fast enough such that turbulence in the downdraft dominates other factors that contribute to giving the precipitation the appearance of curtains? I recall several situations where precipitation in hook echoes does not exhibit a "curtain" type behavior.

Descent speed was determined by tracking the bottommost part of the rain elements as they fell to the surface. As there aren't "downdraft meters" around for sampling the RFD, I'm unsure what downdraft speed would be required to cause enough turbulence to disrupt the appearance of rain as "curtains" (we have now omitted the description of the rain as curtains throughout the paper). I expect this would be a function of the downdraft width. If the downdraft is sufficiently wide, turbulence will primarily influence the edges, and to the visual observer, curtains would still be apparent in the core of the downdraft.

In the discussion, they speculate as to why we missed a DRC in the hook echo region from previous field studies. It could be that nobody was looking for something so specific. I suspect a review of previous videos may show more of these.

This would not be surprising. While I've seen several other videos with suspicious rain shafts, it takes at least two camera angles and a case near radar to really determine whether it was a DRC or not. [It is] all the more reason for PHOTEX type projects.

[Minor comments omitted…]

Reviewer reference:

Atkins, N. T. and R. M. Wakimoto, 1991: Wet microburst activity over the southeastern United States: Implications for forecasting. *Wea. Forecasting*, **6**, 470-482.