PICTURE OF THE MONTH

On the Decay of Supercells through a “Downscale Transition”: Visual Documentation

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ABSTRACT

Photographic and mobile-radar documentation of the dissipation of a supercell and a severe convective storm that had not yet developed into a mature supercell are discussed. It is hypothesized, based on these cases and on others, that when a low-precipitation or classic supercell and/or a developing supercell moves into an environment of cooler surface temperatures and a strong capping inversion, it eventually dissipates through a process of “downscale transition,” in which vertical shear tilts the updraft more in the downshear direction as the CAPE decreases, and the updraft becomes narrower as the storm dissipates. During the downscale transition, it is possible that a cold pool or lack thereof may play a role, but the documentation in the cases detailed herein is not adequate to address this issue.

1. Introduction

Severe convective storms have been the subject of extensive study, owing to the damage inflicted by them via their high winds and large hail. Most studies have therefore been undertaken with the primary objectives of understanding the tornadoes, straight-line winds, and hail produced by them (e.g., Doswell 2001) and understanding the initiation of the convective storms that produced them (e.g., Weckwerth et al. 2004). To the best of the author’s knowledge, relatively little attention has been given to how supercells dissipate; most studies have thus far addressed how they form and how they behave when they are mature (see Bluestein 2007 for a summary).

In many instances, supercells are transformed into multicellular lines as the evaporatively cooled surface outflow air underneath them (their cold pools) forces new convection along arc-shaped boundaries, marking a gust front (e.g., Weisman and Klemp 1984). In other cases, lines of individual supercells merge when neighboring right- and left-moving split cells collide and interact (e.g., Bluestein and Weisman 2000). It is also possible that supercells can be transformed into multicellular lines when a cold front or bore (Koch and Clark 1999) overtakes them and a line of convection is forced. When a larger-scale cold pool is produced, the organization of the convection (the area and intensity of the updraft regions and the radar echoes) changes from that of a relatively small spatial scale (≈10 km) up to that of the mesoscale (approximately 10–100 km). If the cold pool continues to build in intensity and depth, the horizontal vorticity generated at the leading edges of the gust front may eventually overwhelm the environmental horizontal vorticity (vertical shear) of the opposite sign, so that the circulation becomes shallower and tilted more in the upshear direction. This imbalance can lead to weakening of the leading-line convective updrafts (Rotunno et al. 1988; Weisman and Rotunno 2004), and, in extreme instances, to complete cell or system decay, depending on the level of the LFC and the strength of any cap, among other things. In my experience, when a convective system decays, the entire convective cloud base typically erodes from below, leaving behind midlevel cloud debris and an anvil aloft, and sometimes low-level arcus clouds.

However, in some circumstances the organization of
the convection does not proceed upscale but instead proceeds in the opposite direction. Bluestein and Parks (1983), Bluestein (1984), and McCaul et al. (2002) described the visual aspects of the decay of some low-precipitation (LP) supercells and tall cumulus towers that had been initiated in a supercell environment—that is, one of relatively high vertical wind shear (in excess of \( \sim 20 \text{ m s}^{-1} \) over the lowest 6 km) and convective available potential energy (CAPE, \( \geq \sim 1500 \text{ J kg}^{-1} \)) (Weisman and Klemp 1982) It was found that the main convective cloud tower (in which it may be presumed that there was an updraft), which was rotating, became narrower and narrower as the storm or tower dissipated. An anvil and possibly midlevel cloud debris did, however, persist.

It is therefore thought that the aforementioned “downscale” mode of dissipation may be unusual because little if any rain falls from the storm’s convective cloud tower; if any does fall, it falls relatively far from the updraft, under the downstream anvil. Thus, there

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**Fig. 1.** Surface plot for Oklahoma and its immediate surroundings at 1900 CDT 26 May 2004 (0000 UTC 27 May). Temperature and dewpoint are plotted in degrees Celsius; sea level pressure given in hectopascals \( \times 10 \) with the leading “10” or “9” omitted; whole (half) wind barb denotes \( 5 \) (2.5) m s\(^{-1}\). Dashed line denotes approximate location of dryline.

**Fig. 2.** (a) Sounding and (b) hodograph for Norman, OK, at 1900 CDT 26 May 2004 (0000 UTC 27 May). In (a), half, whole, and flag wind barbs denote 2.5, 5, and 25 m s\(^{-1}\), respectively; pressure is plotted to the left (hPa); temperatures are shown at bottom (°C). In (b), zonal and meridional components of the wind (m s\(^{-1}\)) are plotted along the abscissa and ordinate, respectively; pressure is plotted in hectopascals.
cannot be an extensive, strengthening surface cold pool along the leading edge of the updraft that could act to decrease the vertical excursions of ambient air being lifted to its lifting condensation level in the main updraft; hence, the main convective updraft should persist if the environmental parameters do not change. If there were a surface cold pool associated with the light precipitation under the anvil, it would produce horizontal vorticity at its rear edge (in the same sense as that associated with the environmental shear), which could increase the tilt of the convective tower in the downshear direction.

For over a decade, the visual appearance of the right rear flank of a number of supercells, where tornadoes may appear, has been correlated with close-range radar-reflectivity data from mobile Doppler radars (e.g., Alexander and Wurman 2005; Bluestein et al. 2007). Such documentation is better than that which was available when only more remote, operational radar data were available with coarser spatial resolution and when
data were not usually available near ground level, owing to the curvature of the earth’s surface. In some instances (e.g., 30 April 2003 and 26 May 2004), which have not usually been intentional, the demise of supercells or cloud towers initiated in a supercell environment has been documented both visually and by close-range radar.

On 26 May 2004, a nontornadic supercell decayed as it moved across central Oklahoma and approached Oklahoma City. Data were collected (sector scans at low elevation angle only) by the UMass X-Pol, a polarimetric, mobile, X-band radar designed and built at the University of Massachusetts at Amherst (Bluestein et al. 2007). In this study, only the radar reflectivity and Doppler velocity will be considered (polarimetric variables will not be discussed here). Although the collection of mobile Doppler radar data ceased as the storm weakened, an extensive set of photographs was obtained that visually documents the demise of the storm. The main purpose of this note is to describe this documentation. In addition, on 30 April 2003, a developing convective storm in a supercell environment was documented by an extensive set of photographs, and to some extent, by the same mobile Doppler radar. The dissipation of this storm is also discussed and compared with the dissipation of the other storm.

The documentation of downscale dissipation could be important to numerical modelers, who may need to represent, more accurately, the dissipating stage of a supercell because the decaying storm could have a significant impact on subsequent convective activity by leaving behind a surface boundary and/or by moistening or drying out the boundary layer. In sections 2 and 3, the documentation of the 26 May 2004 and 30 April

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**Fig. 5.** Low elevation angle (approximately $3^\circ$–$4^\circ$) (a) radar reflectivity (dBZ) and (b) Doppler velocity (m s$^{-1}$) from the UMass X-Pol at 1825 CDT (2325 UTC) 26 May 2004. View toward the top of the image is to the north. Constant-range rings shown every 10 km. In (b), the location of the leading edge of the rear-flank gust front is denoted by a curved dashed line; a weak cyclonic vortex signature is indicated by a circle surrounding the Doppler velocity couplet (green–yellow). In (a), the location of the weak cyclonic-vortex signature is indicated by an arrow. The location of the radar is the same as that of the viewer in Fig. 4.
2003 cases, respectively, is presented and in the concluding section 4, the results are summarized and hypotheses for the downscaled transition are offered.

2. The 26 May 2004 case

A storm that formed along the dryline in western Oklahoma (Fig. 1) during the afternoon on 26 May 2004 developed into a classic supercell and produced hail 4.5 cm in diameter, but did not spawn a tornado. The storm formed in an environment of vertical shear of approximately 25–30 m s\(^{-1}\) over the lowest 6 km, a strong capping inversion, and CAPE of almost 3000 J kg\(^{-1}\) (Fig. 2), which is supportive of supercells (Weisman and Klemp 1982). Its formation was slightly unusual because it formed in the presence of a layer of cirrus overcast (Fig. 3), which the author, based on long-term observations, believes suppresses convective development along the dryline, most likely by limiting surface heating, so that convective temperature is more difficult to attain. A tornadic supercell did, however, form to the northeast, north of the cirrus canopy (Fig. 3; just to the west of the ARM site, which is marked), where it was several °C warmer (Fig. 1). The storm that formed in western Oklahoma had a long, narrow, anvil plume that was advected far downstream into Arkansas; it was narrower (on its western side, near the storm’s main convective tower) than the anvil produced by the tornadic supercell to the northeast. No other convective storm was noted in its vicinity (Fig. 3), precluding any interaction between it and outflow boundaries from any other storm.

During the mature stage of the supercell in western Oklahoma, a wall cloud and flared-out base were observed along the southern edge of its rear flank (Fig. 4). Circular striations in the anvil were visible to the south, like those described by Bluestein (1984). Around this time, the radar echo of the storm at a low elevation angle had an appendage on its right rear flank (Fig. 5a) to the rear (west) of the rear-flank gust front, which was marked by an arc-shaped boundary separating receding and approaching flow (Fig. 5b; green–yellow couplet highlighted by a circle). It is not known if the air to the west of the boundary was cool or not in comparison to the ambient air ahead of it. A time series of data (not shown) from the Oklahoma Mesonet (McPherson et al. 2007) station at Minco, which was several kilometers south of the storm (see Figs. 4 and 5), showed only a steady decrease in temperature of ~1°C from 1800 CDT (2300 UTC) to 2000 CDT (0100 UTC), from approximately 30° to 29°C, wind direction from approximately 170°–180°, pressure fluctuations of 0.5 hPa or less, and wind speeds varying from 11–15 m s\(^{-1}\) [the

Fig. 6. (a), (c) Radar reflectivity at (a) 0.5° elevation angle at 1825 CDT (2325 UTC) and (c) 5° elevation angle at 1828 CDT (2328 UTC). (b), (d) Doppler velocity (b) as in (a); (d) as in (c). Data are from the WSR-88D near Oklahoma City (KTLX), on 26 May 2004. Range markers are shown every 15 km. Reflectivity (dBZ) and Doppler velocity (m s\(^{-1}\)) scales are shown at the bottom of each panel. White circles in (b) and (d) refer to Doppler velocity signatures discussed in the text.
maximum gust was at just after 18:30 CDT (00:30 UTC). If there had been a cool gust front, it was not apparent at our location (−10 km south or southeast from the core) either (based on the author’s subjective judgment).

Data from the Weather Surveillance Radar-1988 Doppler (WSR-88D) at Oklahoma City (KTLX) also showed evidence of a rear-flank gust front (Fig. 6b; white circle near appendage seen in Fig. 6a) as a boundary between yellow (receding) and green (approaching) Doppler velocities. Cyclonic and anticyclonic shear signatures were evident at midlevels (∼6 km AGL) (Fig. 6d), which are commonly observed in supercells. A storm motion of ∼30 km h⁻¹ (∼8 m s⁻¹) toward the
east was estimated from the radar echo motion. Because the approaching Doppler velocities seen in Figs. 5b and 6b were approximately 6–9 m s⁻¹, it is concluded that the storm relative outflow behind the boundary was <2.5 m s⁻¹. If the rear-flank, gust-front boundary were two-dimensional and driven by a cold pool, the cold pool must have been extremely weak or shallow or nonexistent because the speed of a density current is proportional to the temperature difference across it and to its depth and to the ambient flow (e.g., Bluestein 2007). This inference depends on how well one can apply two-dimensional density current theory to the region near updrafts or downdrafts in a mesocyclone in a supercell; it neglects any dynamical effects of the mesocyclone and updrafts and downdrafts in the storm. Rear-flank gust-front passages in supercells that are not backed by significant (>1°C), or any temperature drops at all, or by temperature rises have in fact been experienced by the author and documented by Markowski et al. (2002). On the other hand, to the north at the Oklahoma Mesonet site in El Reno (Fig. 7), near the center of the precipitation core of the storm (Figs. 5), the surface temperature fell ~8°C to 20.5°C at 1830 CDT (2330 UTC) (the fall all the way to 20.5°C may have been erroneous, owing to wetting of the sensor and evaporation; from Fig. 7 it is seen that the fall was probably at least ~5°C to 23.2°C); the temperature minimum followed a peak surface wind gust of 20.5 m s⁻¹ and a pressure rise of ~1.5 hPa and fall of ~2 hPa over a ~50-min period; and the wind direction backed from 220° to ~140° over a 30-min period and subsequently veered back to ~180° over the next 2 h. These fluctuations in temperature, pressure, and wind direction are consistent with the passage of a shallow cold pool moving from west to east; however, they were measured in the forward flank of the storm, not in the right rear flank (where no observations were available). A very weak cyclonic vortex signature (green–yellow) was located at the place where the rear-flank gust front met the main body of the radar echo associated with the storm (Fig. 5b). It does not appear that this small vortex passed directly over the El Reno Oklahoma Mesonet site later on, either because it missed the site or because it had dissipated by the time it reached the site.

As the storm matured further, the cloud base associated with the main updraft assumed a bell shape and a laminar appearance (Fig. 8), the latter of which is suggestive of upward-forced, saturated, rising air in a convectively stable environment. The radar reflectivity patterns associated with the storm had a hook (Figs. 9a,b) and a bulging rear-flank gust-front echo to its south (Fig. 9a). By 1925 CDT, the hook echo appeared to have dissipated, but beam blockage precluded good documentation of what happened in this sector of the storm after 1852 CDT. The radar echo of the storm during its mature stage, as depicted by the UMass X-
Pol, was relatively narrow and was elongated in the east-west direction (Figs. 5a, 9); some of this narrowness was likely an artifact due to attenuation, as evidenced by the broader radar echoes seen by the WSR-88D (Figs. 6a, 10a) at a low elevation angle. A weak velocity signature suggestive of a weak rear-flank gust-front boundary was also seen at 1922 CDT (Fig. 10b; white circle). Aloft (∼5 km AGL), a cyclonic–anticyclonic shear couplet signature was still evident at the rear of the storm (Fig. 10d).

The width of the updraft tower, which was cumuliform on its western side but laminar on its eastern side, subsequently decreased (Fig. 11a); the cloud tower then leaned over with height to the east even more, while the laminar cloud base remained attached, but eventually diminished in width (Figs. 11b–g). A funnel cloud was observed briefly (not shown) pendant from the underside of the leaning tower, which changed from laminar in appearance to ragged looking as it dissipated, as has been observed in many other cases (Bluestein 1988).

Just before the storm was beginning to dissipate, the National Weather Service issued a severe thunderstorm warning for it, albeit for the area far to the east, downstream from the main cloud tower, where heavy pre-
cipitation was falling. Most of the precipitation region was separated from the leaning, dissipating main updraft tower; the western edge of the radar echo came to a point within a few kilometers of the tower (Figs. 12c,g). No thermodynamic measurements were available to document the existence of a cold pool at this time. [Four Oklahoma Mesonet sites around Oklahoma City that are now operational were not available in 2004 (www.mesonet.org/sites/).] This supercell had the characteristics of a classic supercell in that there was a visually opaque precipitation core, but was like an LP supercell in that the updraft base was not near any precipitation. A signature of a rear-flank gust-front boundary was still apparent at 1934 CDT (Fig. 12b; white circle) but not at 1949 CDT (Fig. 12f). Aloft, there was a weak cyclonic–anticyclonic vortex signature at the rear of the storm at 1936 CDT (Fig. 12d; white circle), which was much less well defined at 1949 CDT (Fig. 12h; white circle).

3. The 30 April 2003 case

A description of this case will be briefer than that of the previous case because the storm to be described lasted for a much shorter time and was less significant. Narrow convective storms developed along the dryline during the afternoon of 30 April 2003 (Figs. 13, 14a) in
an environment supportive of supercells (Fig. 15—CAPE $\sim$2800 J kg$^{-1}$, shear in lowest 6 km of $\sim$20 m s$^{-1}$) and having a large capping inversion.

One storm produced hail 4.5 cm in diameter near Clinton, OK, at 1923 CDT (0023 UTC). The radar appearance of this storm looked like that of a developing supercell: the western, upshear end of the echo came to a point while the eastern, downshear side fanned out in a “V” shape (Fig. 16), which is thought to represent the flow of hydrometeors around a strong updraft (McCann 1983). A weak cyclonic–anticyclonic shear signature was noted at mid to upper levels ($\sim$8 km AGL) (Fig. 16h; white circle). No hook echo or well-defined vortex signatures (not shown) were discernible at low levels (Figs. 16a–f). There was evidence of a weak rear-flank gust front to the west of the UMass X-Pol at 1925

Fig. 11. Sequence of images depicting the dissipation of the updraft tower of the supercell. Wide-angle view is to the (a) north-northwest, (b) north, and (c)–(g) northeast, at (a) $\sim$1936 CDT 26 May 2004 (0036 UTC 27 May) and (b)–(g) $\sim$1939–2000 CDT. The UMass mobile W-band radar is visible in the lower center of (b); a radome at OKC is visible at the lower right in (b)–(g). In (c)–(g), a tornadic supercell is seen on the horizon to the northeast. From photographs © H. Bluestein.
and 1940 CDT (0025 and 0040 UTC) (Figs. 16b,d); at 1925 CDT (0000 UTC) the 0 isodop, which was oriented normal to the radar beam (white shading and dashed line) to the west of the radar, separated the approaching flow (~4 m s⁻¹) from zero receding–approaching flow; at 1940 CDT (0040 UTC) the rear limits of the area of approaching flow are marked by a dashed line. As in the 26 May 2004 case, the storm relative outflow behind the rear-flank gust front was negligible; suggesting that any cool temperature anomaly of the surface air behind the gust-front boundary must have also been small. The main supercell characteristic that it had was that it was relatively long lived, with a persistent updraft base; there was also evidence of storm splitting (Fig. 14). No other convective storms were evident in the immediate vicinity of the storm depicted in Fig. 16 (Fig. 14), so there could not have been any interactions between this storm and any outflow boundaries produced by neighboring storms. There were echoes at some times to the north (Figs. 14a,c,d,e), but these tended to dissipate or move farther away downstream with respect to the flow at the surface (Fig. 13).

The storm never developed into a mature supercell because further development was arrested. The laminar cloud base narrowed with time and assumed a cone-shaped appearance (Figs. 17a,b). Vigorous cumuliform growth was visible in Fig. 17b on the tower’s west side. The tower subsequently leaned over with height (Fig. 17c) and eventually disappeared.

4. Summary and discussion

In both of the cases just described, the convective storm decayed as the main convective tower leaned
over more in the downshear direction and became narrower; anvil material and precipitation fell far from the main tower, tens of kilometers or more in the downshear direction. This mode of dissipation is termed “downscale transition.”

In the downscale transition mode, it is hypothesized that baroclinic generation of horizontal vorticity near the surface is not significant because any cold pools that have formed are far removed from the main updraft (owing to the tilt of the updraft or because cyclonic flow
at the surface is not strong enough to advect cold air from the forward-flank cold pool back around to the rear flank) and/or not ahead of the rear-flank gust front. Instead, it is hypothesized that the storm dissipates when the main convective tower moves into a region of cooler surface air, so that the CAPE is decreased and air parcels eventually fail to attain convective temperature, owing to a capping inversion. In the case of the 26 May 2004 (30 April 2003) storm, the surface temperature, which was 28°–29°C (Figs. 1 and 2) [27°–28°C (Figs. 13 and 15)] where the storm dissipated, was well below the convective temperature of ~33°C (32°C). The weaker, less buoyant updraft in the more capped environment would tend to lean more in the direction of the strong environmental shear (e.g., Weisman 1993; Fig. 14a).

Suppose that the updraft profile across the tower is Gaussian (Kyle et al. 1976) and that a minimum updraft speed is required to sustain the convection (i.e., to draw boundary layer air up to the level of free convection). Then, as the maximum magnitude of the updraft decreases, the width of the updraft capable of sustaining convection also decreases. This hypothesis could be tested with in situ measurements of vertical velocity. Measurements of surface temperature and other parameters need to be made in the vicinity of the main tower to determine the extent of any nearby cold pool. It is expected that many low-precipitation (LP) supercells dissipate via downscale transition, whereas only those classic supercells that move into a region of cooler surface air capped by a layer of warm air aloft and in which the cold pool becomes separated from the main updraft tower dissipate via downscale transition. What would make the cold pool in a classic supercell (as opposed to that of an LP supercell, when there is little if any rain) become separated from the main updraft is not known. Two possibilities are that (i) the effects of deep vertical shear in the environment overwhelm the baroclinic generation of horizontal vorticity at the leading edge of the surface cold pool behind the rear-flank gust front or that (ii) the rear edge of the cold pool under the anvil generates horizontal vorticity in the same direction as that associated with the environmental vertical shear. Factors that affect the cold

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**Fig. 15.** As in Fig. 2, but for 1800 CDT (0000 UTC) 30 Apr 2003.
pool such as the water droplet size spectrum (the rate of evaporation depends on droplet size; Cohen and McCaul 2006), the entrainment of environmental dry air, and seeding from upstream anvils (Rasmussen and Straka 1998) could also play important roles.

The downscale transition process is one that may be dependent on a change in external parameters; it is not known what the effect of a buildup with time of a cold pool would be. In some instances, changes in the large-scale forcing or shear or a collision with another cell might build up a cold pool. Numerical simulations of supercells moving into cooler surface air [Richardson et al. (2000) considered variations in moisture] might be able to clarify the downscale transition process.

Storm spotters must be aware that when some supercells decay, heavy precipitation and hail may be far removed from the main convective tower, the location where spotters position themselves to look for evidence of tornado formation. When the precipitation is far from the main updraft tower, and the tower begins to lean over more with height, then dissipation is probably imminent.
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Fig. 17. Images of a dissipating convective storm on 30 Apr 2003 in western Oklahoma, approximately 5–10 km northeast of Clinton. Wide-angle views in (a) and (b) are to the north-northwest at −1935 CDT (0035 UTC); view in (c) is to the north-northeast at −1959 CDT (0059 UTC). The UMass X-Pol is visible in (a) and (b). In the lower-right-hand corner of (b), a similar convective tower is visible far to the north-northeast. From photographs © H. Bluestein.


