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# Bow Echo and Mesovortex Evolution during the 2 May 2007 North Texas Derecho

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ABSTRACT

On 2 May 2007, a derecho-producing mesoscale convective system tracked across west-central and north Texas, producing damaging wind speeds up to 40 m $s^{-1}$ (78 kt). Damage included loss of roofs, overturning of trucks and manufactured homes, and several downed electrical towers. Some of the most intense damage occurred in association with deep mesovortices (≥3 km AGL) along the leading edge of the line of storms. The event began as a cluster of storms in eastern New Mexico and west Texas that evolved into a line-echo wave pattern, and finally transitioned into a larger bow echo as it moved into north Texas. The derecho occurred in a thermodynamic environment characterized as moderately unstable, with weak vertical wind shear and weak synoptic-scale forcing for vertical motions. Some studies suggest that the thermodynamic environment on this day supported a derecho, but other research utilizing numerical simulations indicate that the vertical wind shear was too weak to sustain the elevated rear-inflow jet and deep mesovortices that occurred in this case. Several mesovortices, with average lifetimes of 12 min and depths ≥3 km, were identified within 97 km (60 mi) of the nearest network radar. This event both supports and contradicts various aspects of prior research on derecho evolution and behavior.

## 1. Introduction

Convective wind events in the United States produce hazards to life and property on a wide range of spatial and temporal scales. Widespread convective wind events, known as derechos, were recognized first by Hinrichs (1888), and later by other investigators, as significant weather events that merit attention and study for improved forecasting and mitigation. Fujita (1978) recognized the bow echo as a radar signature associated with damaging winds. Almost a decade later, Johns and Hirt (1987) established the first meteorological definition for derechos. Using real time proximity soundings, Evans and Doswell (2001) published a thermodynamic and kinematic characterization of derecho environments. More recent research has focused on the production of low-level mesovortices and their role in producing extreme damaging winds and tornadoes (Weisman and Trapp 2003, Atkins et al. 2004). In this case study, we examine the 2 May 2007 derecho that affected a large portion of west-central and north Texas and caused nearly $2.7 million in damage. This derecho-producing mesoscale convective system (DCS) occurred in a regime of weak synoptic-scale forcing, characterized by moderate instability and weak vertical wind shear along its path.

Objectively analyzed thermodynamic and environmental parameters for this event resemble environments supporting derecho events, as defined in previous studies. However,

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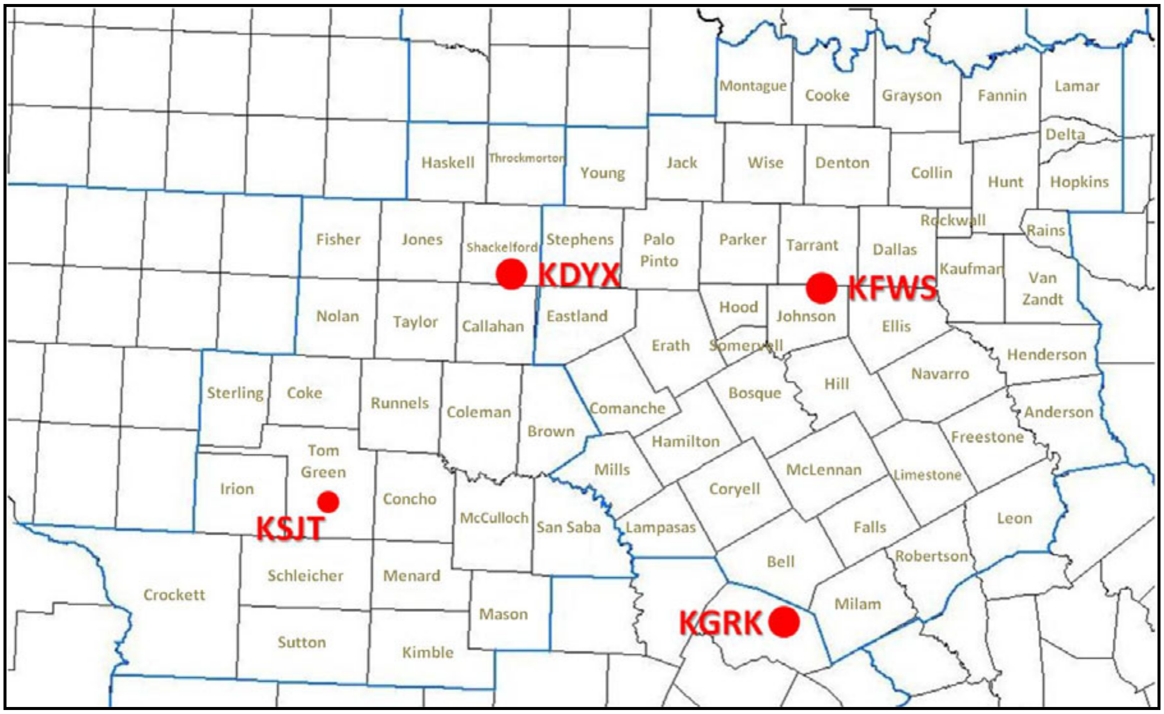



Figure 1: Map of west-central and north Texas, showing the WFO FWD CWA (east, at right) and WFO San Angelo, TX (SJT) CWA (west, at left). Thick blue lines indicate the boundaries of the CWAs. Thin black lines are county borders. County names in the FWD and SJT CWAs are displayed in tan for reference. Locations of the Fort Worth/Spinks (KFWS), Granger (KGRK), Dyess Air Force Base (KDYX), and San Angelo (KSJT) WSR-88D radars are identified by red dots. *Click image to enlarge.*

even though the low-level vertical wind shear was weaker than the Weisman and Trapp (2003) thresholds for low-level mesovortex production, we show that mesovortices of ≥3 km depth were present, some of which produced wind damage equivalent to EF1 intensity on the Enhanced Fujita (EF) Scale (WSEC 2006). The strongest mesovortices and wind damage occurred in the region of Texas commonly referred to as north Texas, and the majority of this paper will focus on the events that occurred there. This region encompasses the county warning area (CWA) of the National Weather Service (NWS) Weather Forecast Office in Fort Worth, TX (WFO FWD) (Fig. 1).

## 2. Data and methodology

Wind and damage reports were obtained using *Storm Data* publication (NCDC 2007). Damage indicators in the EF Scale were used to estimate wind speeds associated with damage reports. While the EF Scale is most commonly used to assess and rate tornadoes, it can be used to relate any wind damage to estimated wind speeds (WSEC 2006).

Meteorological data analyses included output from the North American Mesoscale (NAM) (Janjic et al. 2005), Global Forecast System (GFS) (Environmental Modeling Center 2003), and Rapid Update Cycle (RUC) (Benjamin et al. 2004) models. Thermodynamic and kinematic analyses were completed using the RUC model and RUC-based mesoanalysis graphics (Bothwell et al. 2002) of the Storm Prediction Center (SPC) [available online at http://www.spc.noaa.gov/exper/mesoanalysis/]. To represent the atmosphere over the area of interest in north Texas, downstream of the DCS, 2100 UTC was chosen as the best hour for thermodynamic and kinematic analysis. At that time, the DCS was about to enter the western fringes of the WFO FWD CWA.

Several WSR-88D radars were used to analyze the DCS. Due to its proximity to the DCS, the unit at Fort Worth/Spinks, TX (KFWS) was preferred for radar analysis of the bow echo and mesovortices as they tracked through the FWD CWA. However, radar data from the Granger, TX WSR-88D radar (KGRK) also assisted in storm-attribute analysis. In west-central Texas, the Dyess, TX radar (KDYX) was preferred for its close proximity to at least two mesovortices. Radar locations are shown in Fig. 1.

### 3. Damage path

The severe weather event on 2 May 2007 fits the definition of a derecho in Johns and Hirt (1987): a concentrated area of convective wind gusts ≥25 m $s^{-1}$ (50 kt) with a major axis length ≥400 km (250 mi). Within the area, there also must be at least three reports of wind gusts ≥33 m $s^{-1}$ (65 kt) and/or (E)F1 damage separated by at least 64 km (40 mi). A plot of the storm reports (Fig. 2) shows the area of severe winds and damage was along a narrow corridor ~80 km (50 mi) wide. Based on the area of wind gusts and damage, it appears that the definable derecho event began around 1800 UTC as the DCS was near San Angelo, TX.

Wind damage in the derecho consisted of numerous downed power lines, bent business signs, broken or downed trees and tree limbs, blown out windows and roof damage. More substantial damage included partial or complete loss of roofs, collapsed walls, downed electrical towers, and overturning of trucks and manufactured homes. Some of the most intense damage occurred in the WFO FWD CWA, in association with mesovortices along the leading edge of the DCS.

Four tornadoes occurred as the DCS tracked through west-central Texas (the WFO SJT CWA). A fifth tornado occurred in the WFO FWD CWA, but was spawned by an isolated

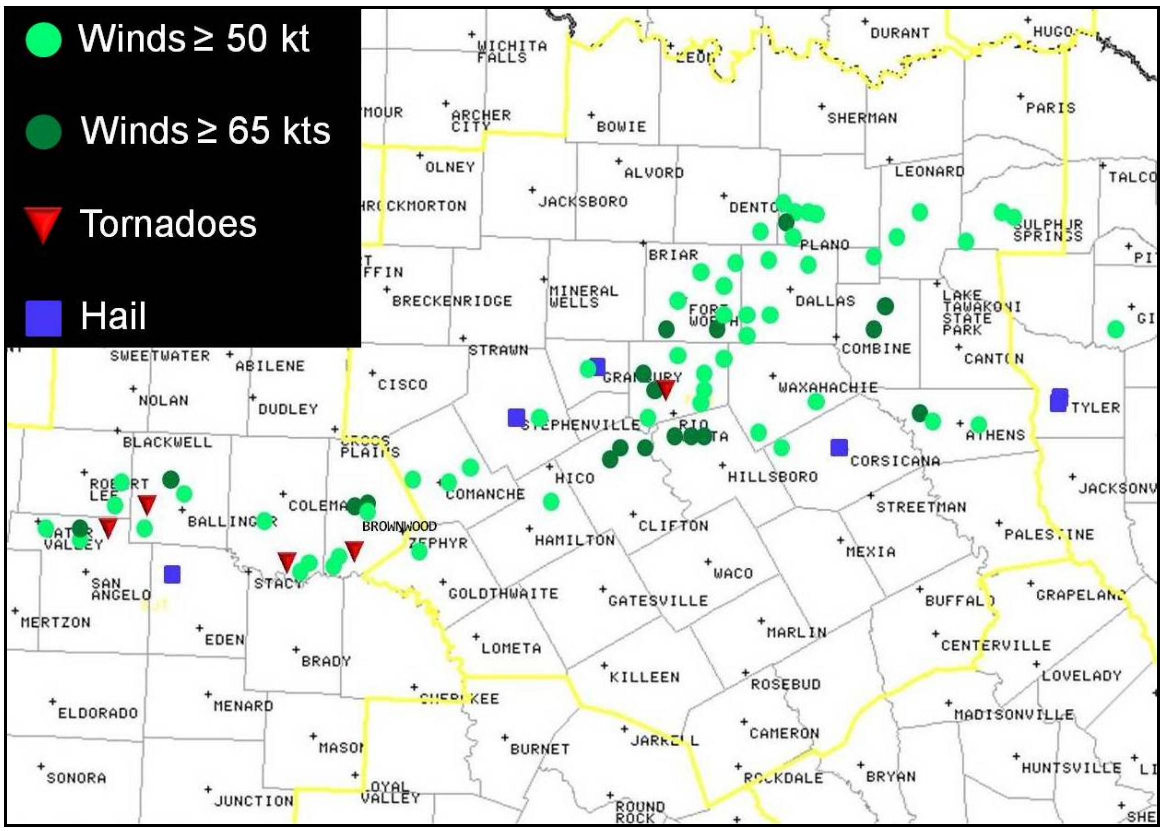



Figure 2: Plot of storm reports across Texas from the 2 May 2007 derecho. Light green dots are wind gusts ≥25 m $s^{-1}$ (50 kt), dark green dots are wind gusts ≥33 m $s^{-1}$ (65 kt), red triangles are tornadoes, and blue squares are hail ≥1.9 cm (0.75 in.) in diameter[1]. Thick yellow lines are NWS CWA boundaries, gray lines are county boundaries, and thick black lines are state boundaries. *Click image to enlarge.*

[1] At the time of the event, 1.9 cm (0.75 in) was the severe hail-diameter threshold. The national change to 2.5 cm (1 in) severe hail criteria occurred in 2010.

storm that developed ahead of the DCS. While moving across west-central Texas, the DCS exhibited a line-echo wave pattern (LEWP) on radar reflectivity displays, with embedded supercells and bow echoes. The four tornadoes in west-central Texas do not appear to have been caused by mesovortices; but rather by storms exhibiting supercell structure within the LEWP.

## 4. Synoptic and mesoscale analysis

The DCS developed between two upper-level perturbations (Fig. 3). The first was an upper-level low moving out of Oklahoma and over eastern Kansas. The second was an approaching upper-level trough over New Mexico. During the course of this event, the 300 and 500 hPa jet streaks associated with this second system remained behind the upper-level trough. The flow along and ahead of the DCS was characterized by weak winds that averaged 2.5–5 m $s^{-1}$ (5–10 kt) at the surface and 10–18 m $s^{-1}$ (20–35 kt) in the mid and upper levels (500 and 300 hPa) of the troposphere.

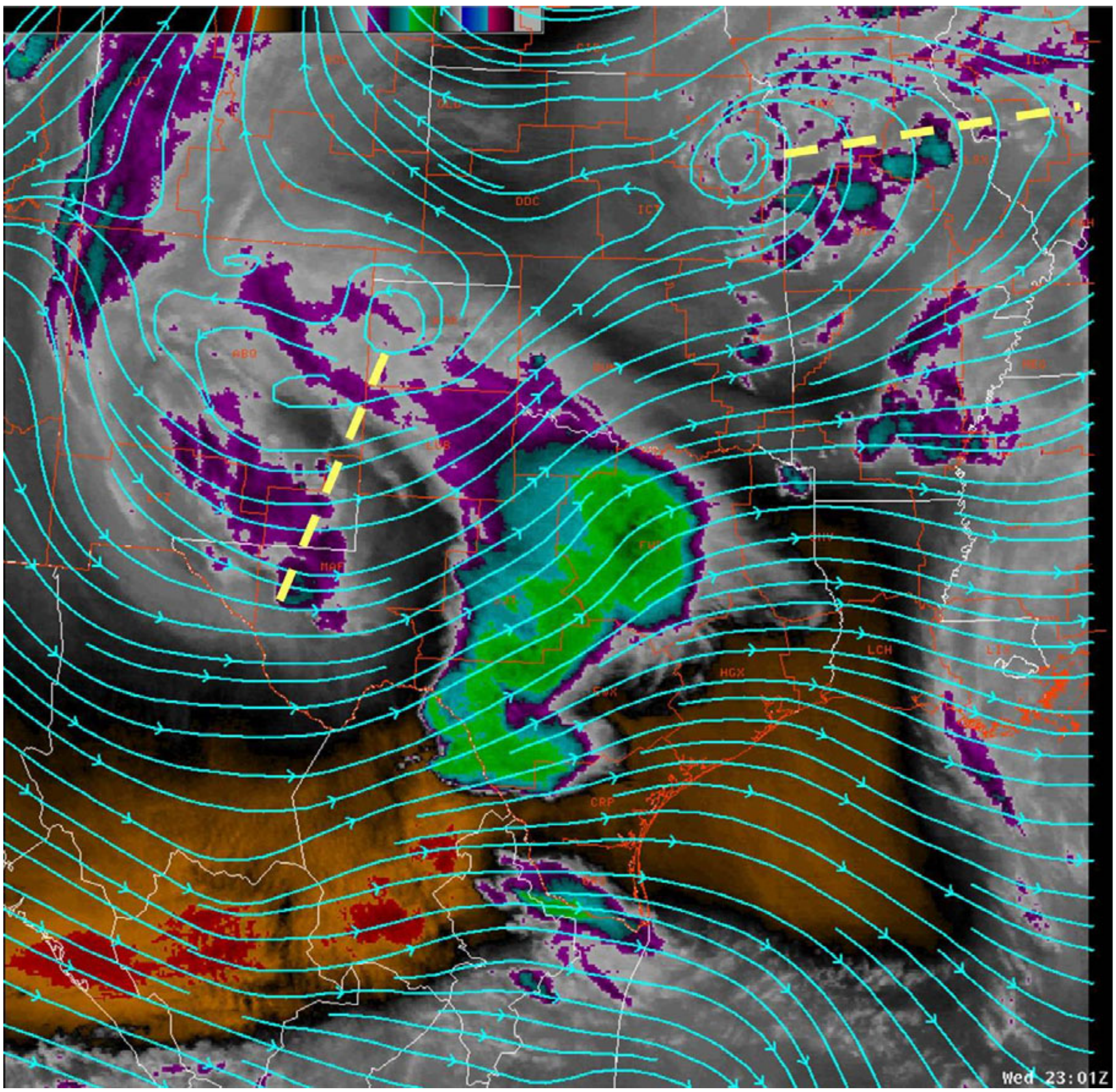



Figure 3: GOES 6.7 µm water-vapor loop from 1601–2301 UTC 2 May 2007 with RUC 500 hPa wind streamlines overlaid. Bright green colors associated with the coldest cloud tops identify the DCS as it was moving across Texas. Dashed yellow lines on the last image of the animation represent the location of each trough. *Click image to play video.*

The storms that evolved into the DCS initiated in eastern New Mexico and west Texas during the local early morning hours of 2 May 2007. These storms developed ahead of a strong shortwave disturbance moving past the upper-level trough over New Mexico. Strong diffluence in the upper levels and moderate instability on area RUC soundings was noted in the area where storms developed. As the storms entered Texas and began evolving into the DCS, the strongest dynamic forcing for large-scale ascent remained behind the DCS with the approaching upper-level trough (Fig. 4). In the lower levels, warm air advection in the 850–700 hPa layer was observed over the southern half of Texas, but the strongest warm air advection remained south of the track of the DCS and likely did not contribute to large-scale ascent along its path (Fig. 5).

As the DCS moved eastward across Texas, it encountered increasing instability, and new surface-based cells repeatedly developed along the gust front (Weisman and Rotunno 2004). The balance between the strength of the cold pool and the shear allowed for deep convection to form continuously on the leading edge of the DCS and likely played a key role in sustaining the DCS for several hours. The synoptic regime on this day most closely resembles Evans and Doswell's (2001) weak-forcing environment, with which the thermodynamic and kinematic parameters of the 2 May 2007 derecho event will be compared in the next section.

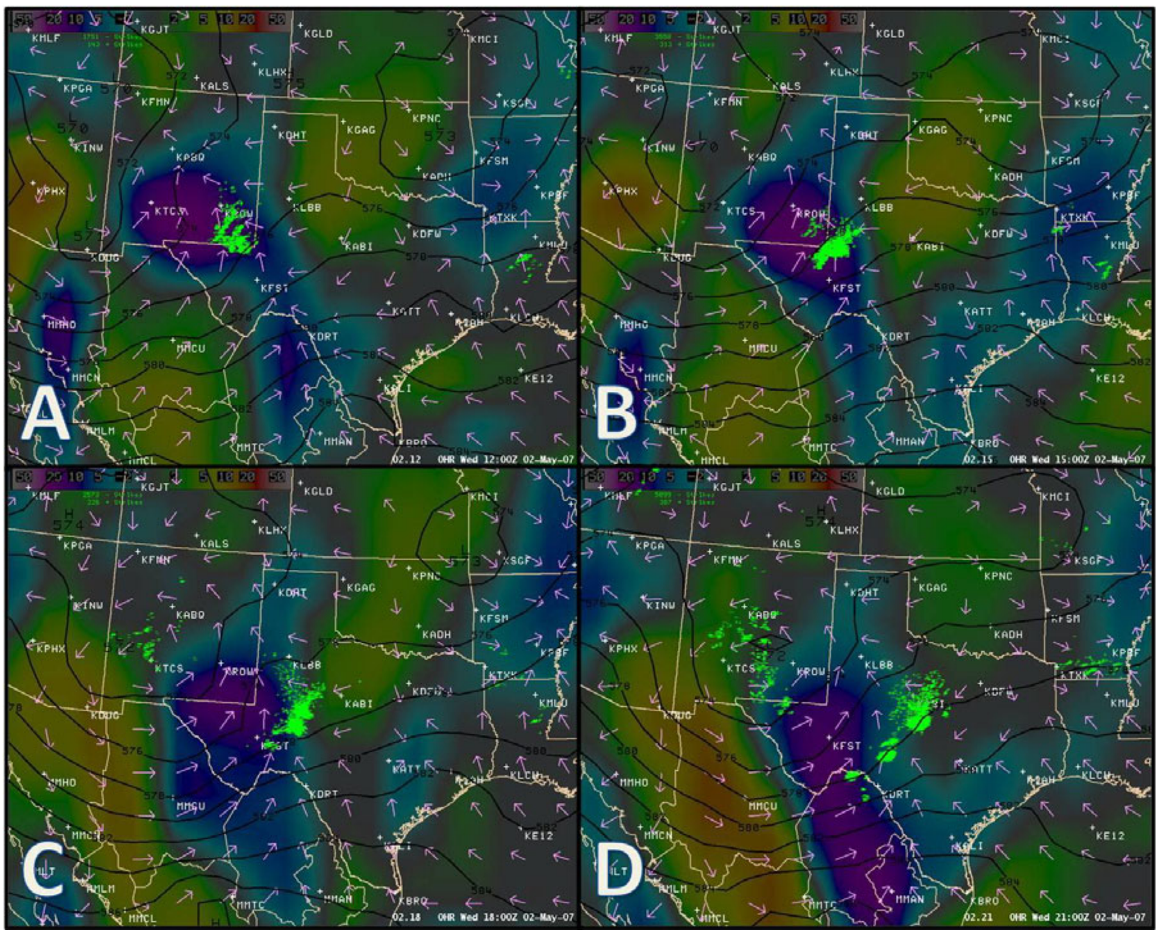



Figure 4: 80-km RUC 850–300-hPa layer Q-vector divergence (colored per scale, interval $1\times10^{-16}$ K m$^{-2}$ s$^{-1}$), $\theta$, and mean layer wind at: a) 1200 UTC, b) 1500 UTC, c) 1800 UTC, and d) 2100 UTC 2 May 2007. Pink arrows represent Q-vectors (in $10^{-12}$ K m$^{-2}$ s$^{-1}$). Black lines are 500-hPa height contours in dam. DCS location is indicated by plots of bright green cloud-to-ground lightning strike markers for the 1-h period ending at each respective time. Quasigeostrophic forcing for ascent is in blue and violet shades. *Click image to enlarge.*

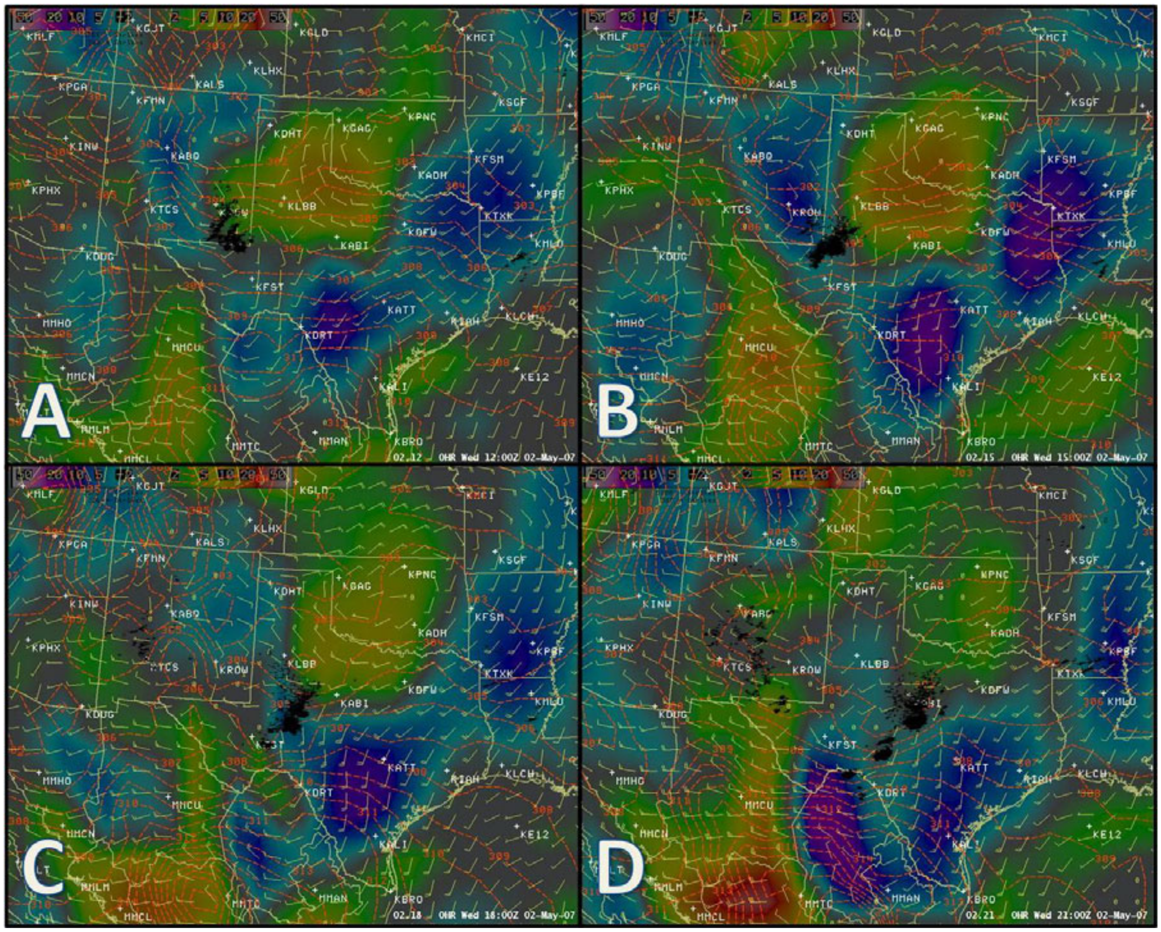



Figure 5: As in Fig. 4, except for 850–700 hPa layer, and DCS location is denoted by black cloud-to-ground lightning strike markers. *Click image to enlarge.*

Johns and Hirt (1987) discovered that most derechos are associated with an east-west thermal boundary at the surface. By contrast, both hand and model analyses showed a quasistationary front aligned northeast-southwest from northern Oklahoma, across central Texas, into west Texas (Fig. 6). At 850 and 700 hPa, a thermal gradient also was located across approximately the same area as the surface front. The DCS moved along and just south of the surface boundary through west-central Texas. Once in north Texas, the DCS moved away from the surface front and intersected a northward-moving, west-southwest to east-northeast oriented boundary produced by convective outflow from the prior day (Figs. 6 and 7). Most of the wind damage in the derecho occurred in the warm sector, south of both the surface front and the outflow boundary.

## 5. Thermodynamics and kinematics

Table 1 compares the thermodynamic and kinematic parameters taken from the RUC on 2 May 2007 at 2100 UTC with Evans and Doswell's (2001) values for derechos in weak-forcing environments. The thermodynamic parameters on this day were typical of previous derecho studies in a similar environment. Southerly winds in the days prior to 2 May 2007 advected rich low-level moisture, with surface dewpoints in the mid 60s to lower 70s ºF (upper teens to lower 20s ºC), from the Gulf of Mexico into the region. By 2100 UTC, a surface moist axis extended from south Texas into northeastern Oklahoma. RUC soundings along the path of the DCS showed precipitable water values of 3.6–4.0 cm. Although these values do not match those in events such as the 8 May 2009 derecho (Coniglio et al. 2010), they are above normal for this time of year. High precipitable water values

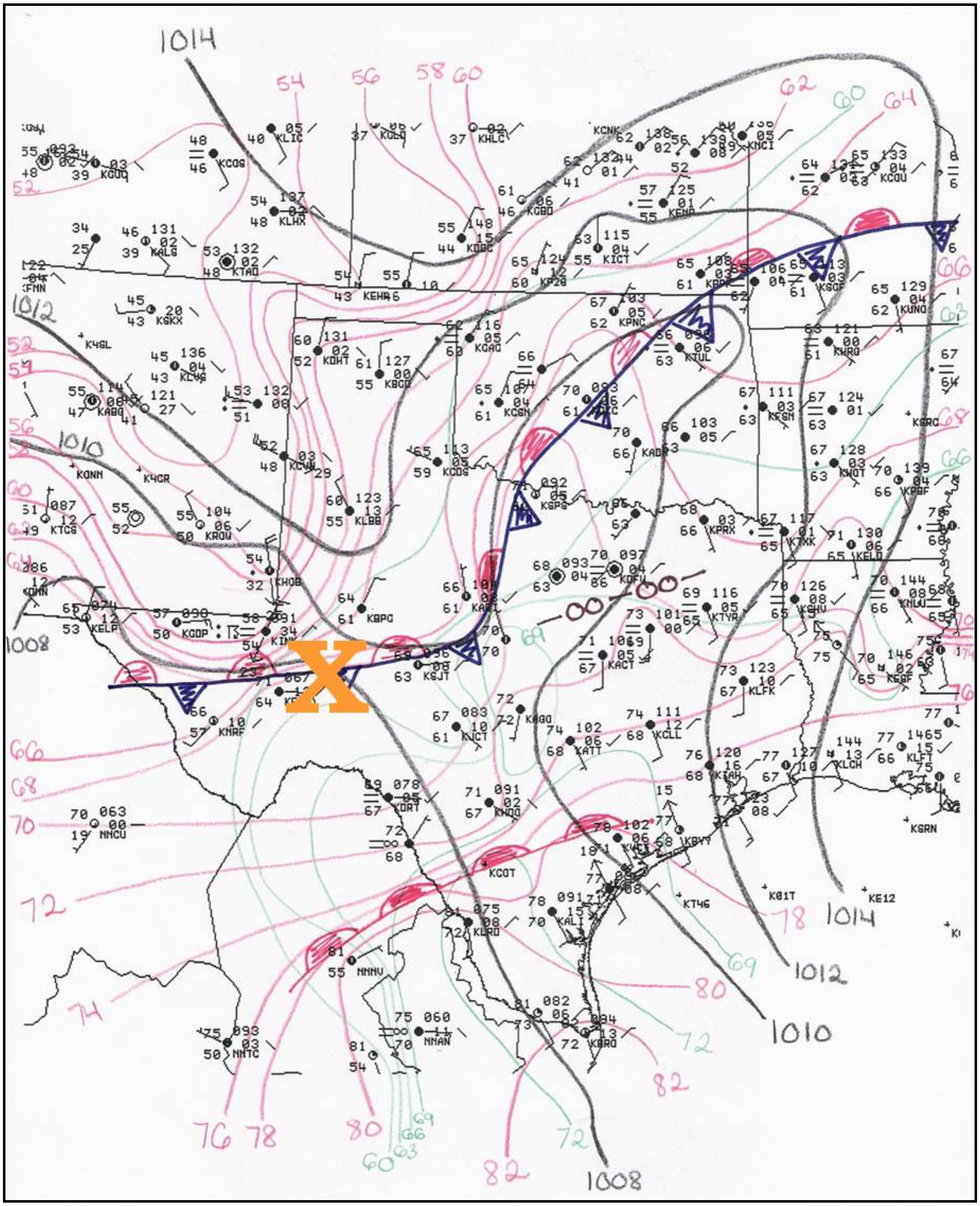
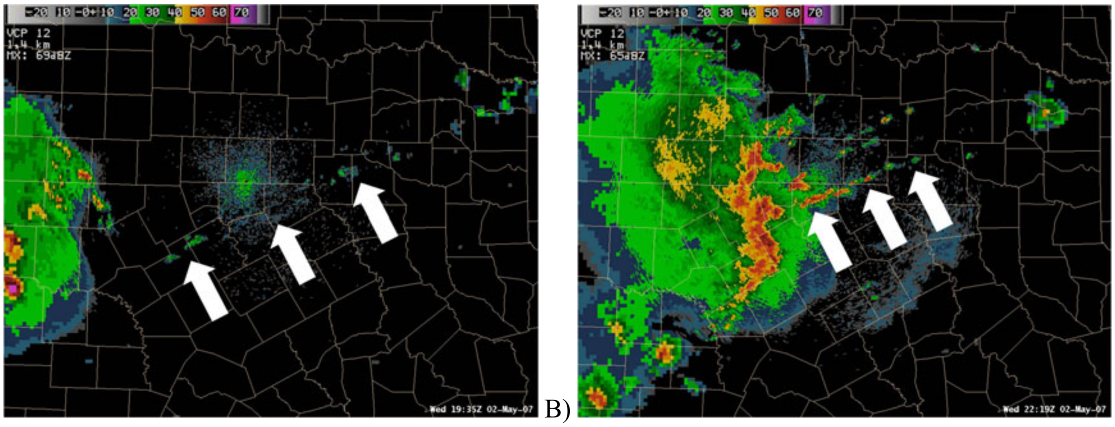



Figure 6: Surface analysis at 1500 UTC 2 May 2007: mean sea-level pressure isobars in black, isotherms in ºF in red, dewpoints in ºF in green, conventional stationary and warm front, and outflow boundary in brown. Composite radar analysis (Fig. 7) was used to locate the latter. Orange X represents approximate DCS location. *Click image to enlarge.*




A) B)

Figure 7: KFWS WSR-88D composite reflectivity (dBZ per scale) at a) 1935 UTC and b) 2219 UTC 2 May 2007. A remnant outflow boundary from convection the day before is highlighted by the white arrows and supports echo development by 2219 UTC (b) ahead of the DCS. *Click images to enlarge.*

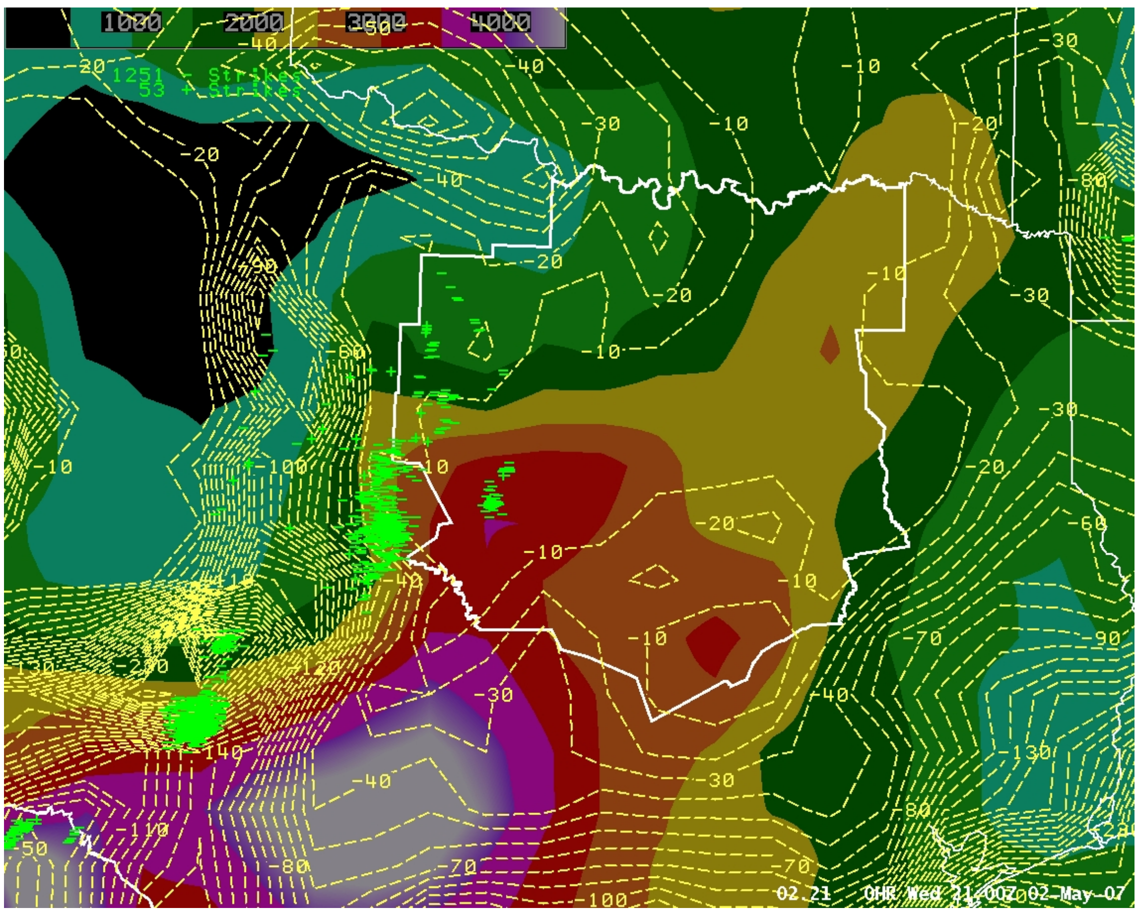



Figure 8: 40-km RUC analysis of MUCAPE (J $kg^{-1}$, shaded per scale) and SBCIN (dashed yellow, J $kg^{-1}$) valid 2100 UTC 2 May 2007. The FWD CWA is outlined by the thick white line, and the location of the DCS is indicated by the bright green cloud-to-ground lightning strike markers plotted for the 15-min period ending at 2100 UTC. *Click image to enlarge.*

Table 1: Comparison of thermodynamic and kinematic parameters for the 2 May derecho with those of Evans and Doswell (2001) for "weak-forcing" events. Note: Evans and Doswell (2001) compared 0–3 km bulk wind differences for all cases, but only used 0–2 km bulk shear for their comparisons of weak-forcing events. The range of values in the parentheses is the 0–2 km bulk shear magnitude used for comparison in the weak-forcing events.

| Sounding Parameter | Evans and Doswell (2001) 25th–75th Percentile | 2 May Derecho 21 UTC Range |
|---|---|---|
| MUCAPE (J $kg^{-1}$) | 2664–4194 | 2000–3000 |
| MLCAPE (J $kg^{-1}$) | 1578–2924 | 1500–2000 |
| SURFACE Δθe (°C) | 18.0–28.0 | 13.0-18.0 |
| DCAPE (J $kg^{-1}$) | 968–1352 | 500–800 |
| 0–3 km WIND DIFFERENCE (m $s^{-1}$) | 8.0–15.0 (7.0–12.0) | 10–15 |
| 0–6 km WIND DIFFERENCE (m $s^{-1}$) | 10.5–20.0 | 10–21 |

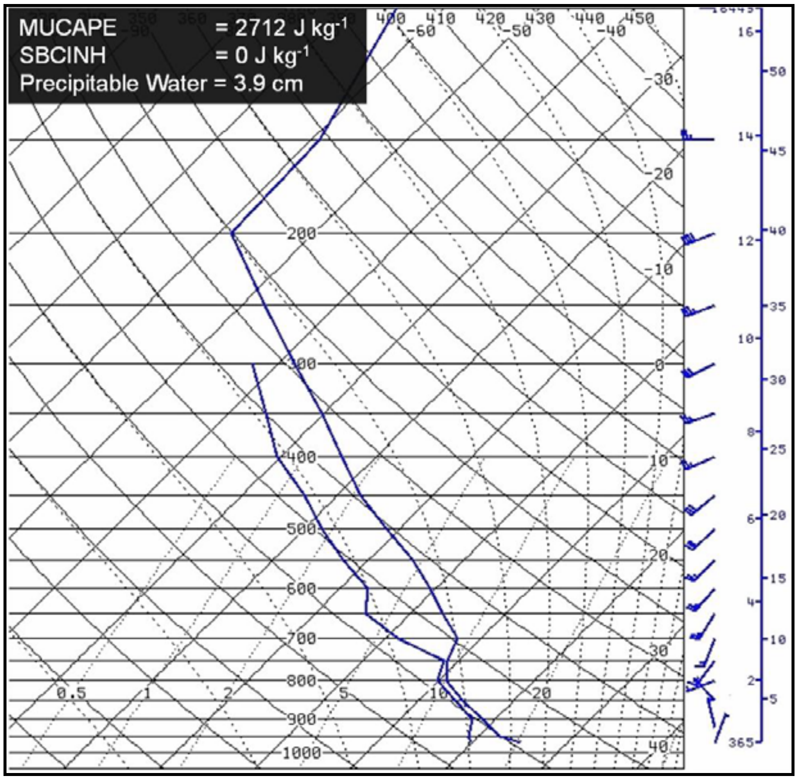
are suspected to contribute to downdraft and cold-pool strength by increasing the mass flow in updrafts and subsequent downdrafts (Coniglio et al. 2010).

Objectively analyzed values of most-unstable parcel CAPE (MUCAPE) across central and north Texas, from the RUC, ranged from around 2000–3000 J $kg^{-1}$ (Fig. 8). The surface-based convective inhibition (SBCIN) was weak over much of north Texas with values <10 J $kg^{-1}$ (Fig. 8). Although the observed 0000 UTC 3 May Fort Worth, TX (KFWD) sounding was incomplete, RUC soundings for Stephenville, TX (KSEP) at 2100 UTC 2 May and KFWD at 0000 UTC 3 May (Fig. 9) also supported CAPE values of 2000–3000 J $kg^{-1}$. These values coincide well with the Weisman (1993) 2000 J $kg^{-1}$ threshold for bow echo development, and also fall within the range of values Evans and Doswell (2001) calculated for derecho events in weak-forcing environments (Table 1).

Observed values of the downdraft CAPE (DCAPE; Gilmore and Wicker 1998) and calculations of $\Delta\theta_e$ across the gust front were used to assess the strength of the cold pool. DCAPE is considered here to be an estimate of the potential for cold pool strength, dependent upon the origins of downdraft parcels in the DCS. Surface $\Delta\theta_e$ might be a more instantaneous measurement of the strength of the cold pool (Evans and Doswell 2001). Surface $\Delta\theta_e$ was computed from the 2100 RUC analysis by taking the difference between the minimum value in the cold pool and a range of 339-344 K immediately ahead of the DCS. A calculated surface $\Delta\theta_e$ range of 13-18 °C fell slightly below the values found by Evans and Doswell (2001) for cold-pool strength in weak-forcing events; and observed DCAPE values of 500–800 J $kg^{-1}$ were also below their range (Table 1).

Substantial research exists on the combined role of shear and cold-pool strength, both for maintaining a long-lived squall line and producing low-level mesovortices (Weisman and Rotunno 2004; and Weisman and Trapp 2003, respectively). Most research has focused on the vertical wind shear in the lowest 2.5–5.0 km of the atmosphere. Simulations by Weisman and Rotunno (2004) found that shear magnitudes of 15–25 m $s^{-1}$ (30–50 kt) in the lowest 2.5–5.0 km of the atmosphere are the most favorable for strong, long-lived squall lines where continuous lifting along the leading edge helps to sustain the system for several hours. Similarly, Weisman and Trapp (2003) note that shear magnitudes ≥20 m $s^{-1}$ (40 kt) in the lowest 2.5–5.0 km are the most favorable for maintaining an elevated rear-inflow jet (RIJ) and developing low-level mesovortices along the leading edge.

Bulk wind differences were obtained using RUC model data; actual and model soundings from Midland, TX, KSJT, KSEP and KFWD; and the Palestine, TX wind profiler. Only data from KSEP and KFWD are displayed in Fig. 10. Objectively analyzed 0–2.5 km and 0–5 km bulk wind differences across west and west-central Texas were 15–20 m $s^{-1}$ (30–40 kt); but observed 0–2.5 km and 0–5 km values in north Texas were only 10–15 m $s^{-1}$ (20–30 kt). The values across north Texas were below the ideal ranges in Weisman and Rotunno (2004) and Weisman and Trapp (2003), but fall within

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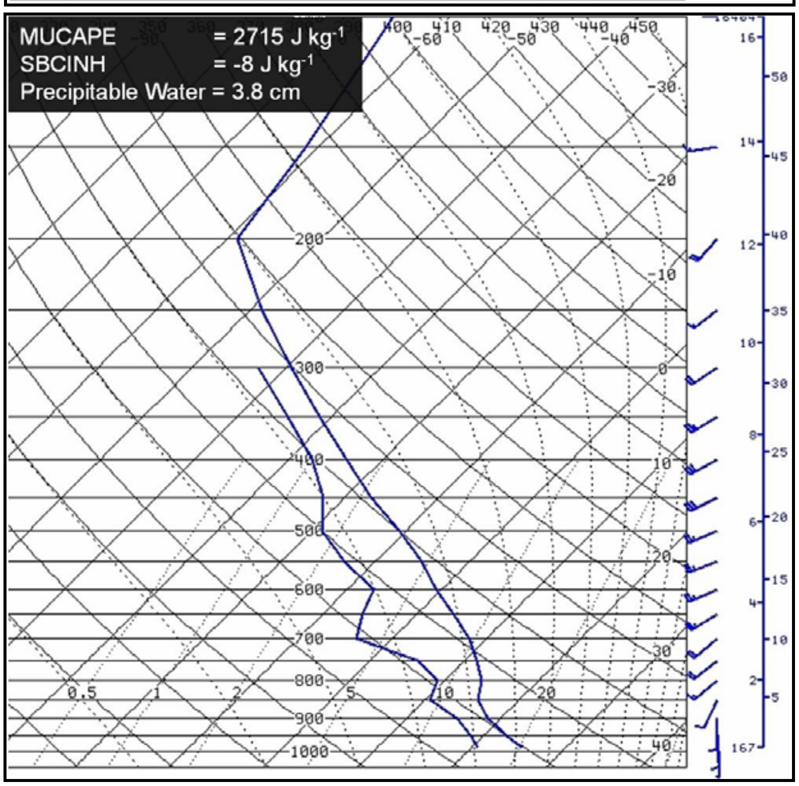



B)

Figure 9: RUC soundings for a) Stephenville, TX, valid 2100 UTC 2 May 2007 and b) Fort Worth, TX, valid 0000 UTC 3 May 2007, each chosen due to its location immediately ahead of the DCS. *Click images to enlarge.*

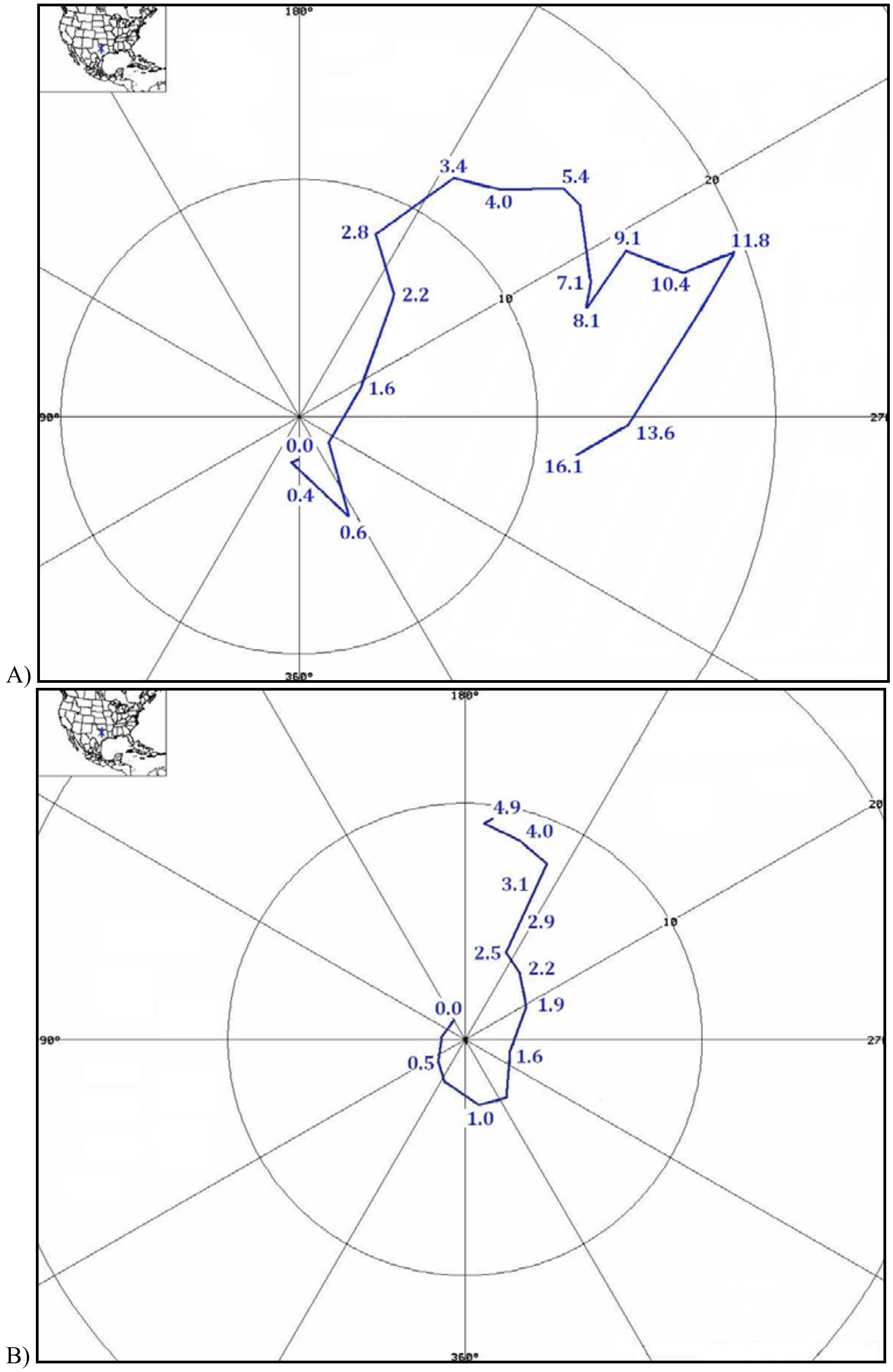



Figure 10: Hodographs from a) RUC at KSEP, 2100 UTC 2 May 2007 and b) 0000 UTC 3 May 2007 sounding at KFWD. Radial intervals are 10 m $s^{-1}$ (20 kt) and blue values are in km AGL. Calculated 0–2.5 km vertical wind difference is 9 m $s^{-1}$ (18 kt) and 3 m $s^{-1}$ (6 kt), respectively. Calculated 0–5 km vertical wind difference is 17 m $s^{-1}$ (33 kt) and 8 m $s^{-1}$ (16 kt), respectively. *Click images to enlarge.*

the middle 50% of those suggested by Evans and Doswell (2001) for derechos in weak-forcing environments (Table 1). The higher values in west and west-central Texas better favored low-level mesovortices, but very few were detected as the DCS moved through this region.

## 6. Storm morphology and radar analysis

This section discusses the overall evolution of the DCS from eastern New Mexico across Texas and additional radar analysis of its components. Extra focus is given to the bow echo that moved across north Texas. Thorough radar coverage of the DCS in north Texas aided analysis of embedded bow echoes and several deep mesovortices that produced the most significant damage reports of the derecho.

### *a. Evolution*

The DCS organized during the morning of 2 May 2007 in west Texas. Prior to that, severe thunderstorms had developed overnight in eastern New Mexico ahead of the approaching upper-level trough. These overnight storms moved north of the surface boundary, weakening in a more stable environment. However, a few storms in west Texas merged into a small bow echo that moved east along the quasistationary surface front and marked the beginning of the DCS. The modal transition from cluster to bow is one of three types that Klimowski et al. (2000) observed in bow echo formation. In west Texas, the bow echo was located over the cool stable air north of the surface front and was mainly elevated. This was indicated by the observed 1200 UTC KMAF sounding and other RUC soundings from the same area. Several reports of large hail up to softball size (11.4 cm) came during this phase. However, the bow echo eventually became rooted in the warm, moist surface air south of the front and transitioned to a damaging wind event. As the DCS continued eastward, additional storms developed along the leading edge, giving a LEWP appearance on radar. Bow echoes and supercells in the LEWP produced much of the wind damage from San Angelo ~90 mi (145 km) east-northeastward to Brownwood, TX (Fig. 11).

As the DCS moved into the western fringes of the FWD CWA, it transitioned into a larger bow echo. During the mature stage, its radar reflectivity appearance resembled Przybylinski and DeCaire's (1985) Type I DCS, which is characterized by an unbroken line echo up to 250 km long and includes up to three embedded bow echoes. The DCS was asymmetric with a large area of stratiform rain mainly behind the northern end. Neither a comma-head appearance on radar nor a book-end vortex in the storm relative mean radial velocity (SRM) images could be identified.

The RIJ, which remained elevated behind the leading edge of convection, was a factor in maintaining the DCS for several hours. Cross sections from KFWS clearly showed the elevated RIJ, and also that strong, vertical cells were persistent along the leading edge of convection (Fig. 12). This appears to contradict the simulations run by Weisman and Trapp (2003) where it was observed that in environments where the shear magnitude was weaker than 20 m $s^{-1}$ (40 kt), the RIJ tended to descend to the ground well behind the leading edge of convection.

### *b. Embedded bow echoes*

The first embedded bow echo in north Texas (hereafter referred to as BE #1) became evident at 2210 UTC over eastern Hamilton County (county map in Fig. 1). The parent cell of BE #1 was the remnants from another bow echo that had previously caused wind damage across parts of west-central Texas. BE #1 may have been the result of a merger between the old bow echo and a supercell that had developed ahead of the line along the pre-existing outflow boundary (Fig. 13). Klimowski et al. (2000) observed that bow echoes can often form shortly after a cell merger(s).

Only 20 min after appearing on the KFWS base reflectivity, BE #1 became better-defined in Bosque County, as a rear-inflow notch (RIN) and weak echo channel (WEC) developed behind the apex of the bow. The RIN continued to be indicated by the KGRK radar as the bow echo moved into Hill County. As described by Przybylinski and DeCaire (1985), the WEC is a sign of dry air intruding in to the back edge of the precipitation; and Fujita (1981) suggests that this WEC indicates that the strongest downburst winds are occurring along the leading edge of the bow echo. Dozens of downed trees and damage to 22 structures was reported in the northern part of Bosque County, coinciding with an area along

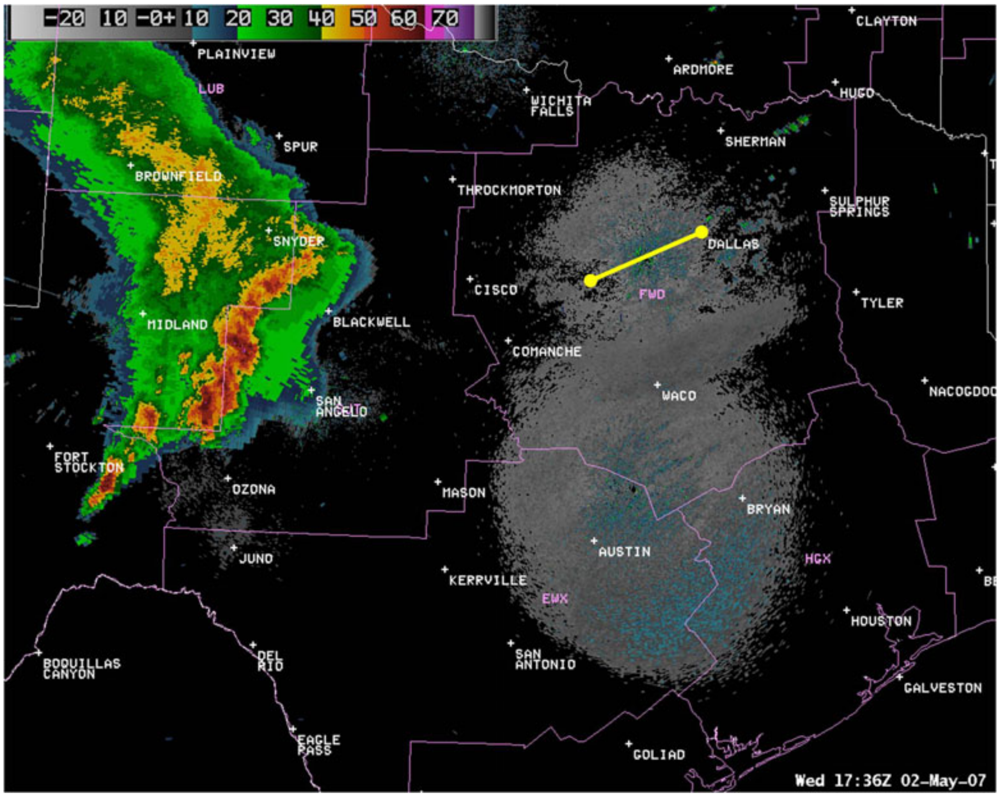



Figure 11: Radar reflectivity mosaic (dBZ) of the DCS from 1736–2354 UTC 2 May 2007. CWA boundaries are outlined in pink. The supercells over southwest Texas produced a few reports of hail, and the second line of storms that developed in central Texas was relatively weak with only a few reports of hail and minor wind damage. The yellow line extending from Dallas to the southwest represents the cross-section in Fig 12. *Click image to play video.*

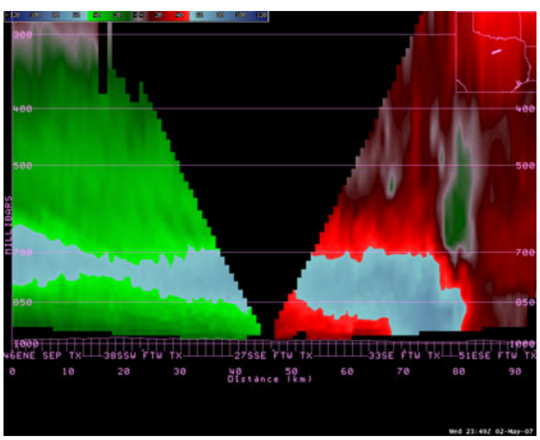
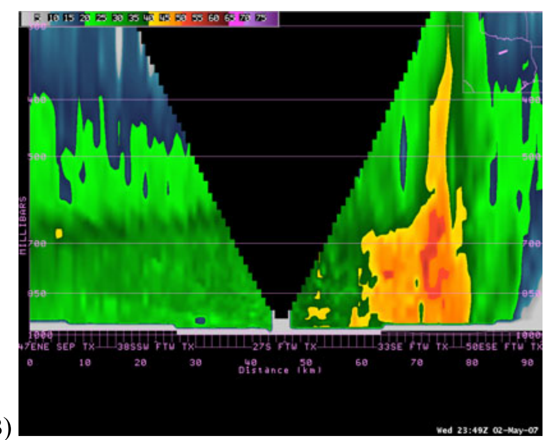
A)  B) 

Figure 12: KFWS WSR-88D cross sections of a) radial base velocity (kt, per scale) and b) reflectivity (dBZ, per scale) through the radar at 2349 UTC 2 May 2007 along a line from approximately Dallas, TX to Granbury, TX, which is ~103 km (64 mi) southwest of Dallas. The leading edge of the DCS already has passed over the radome at this time and was moving eastward. Horizontal pink lines in both images indicate approximate pressure levels in hPa. The blue shading in (a) identifies the elevated RIJ behind the leading edge of convection. Strong and vertically erect convection occurred along the leading edge of the bow echo, ahead of the RIJ. *Click images to enlarge.*

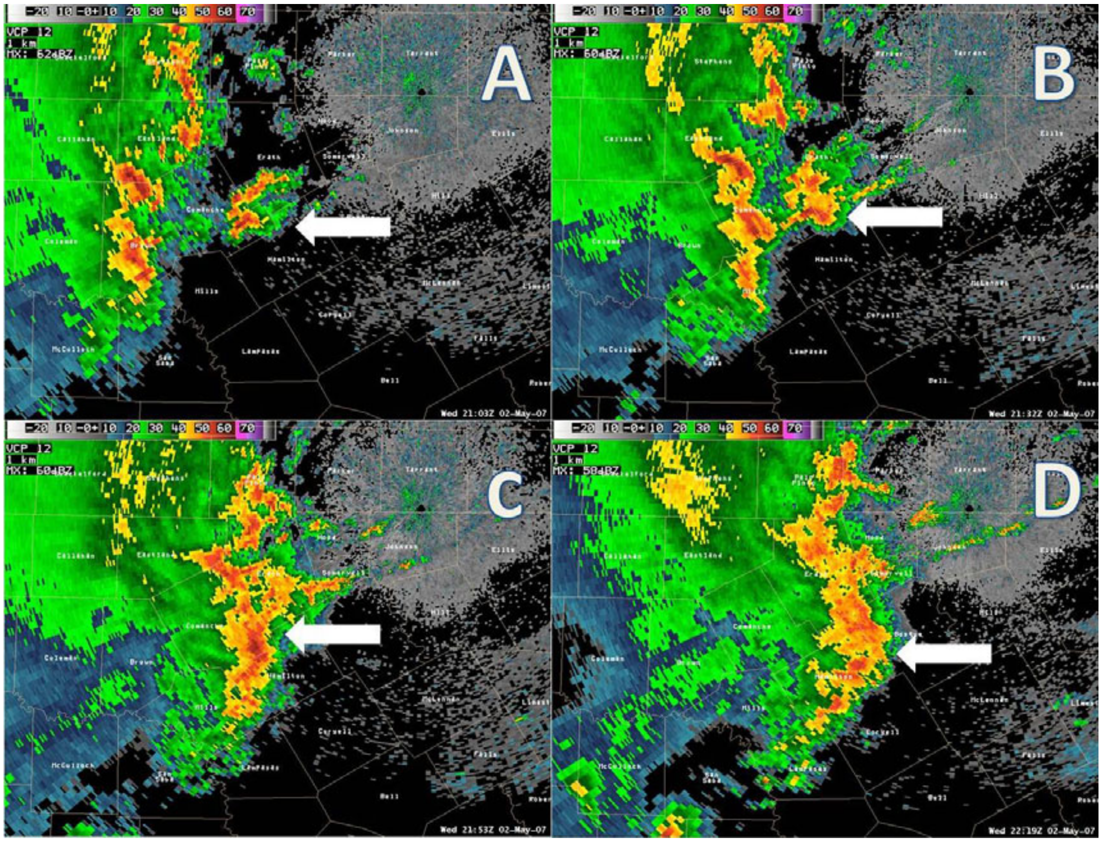



Figure 13: KFWS WSR-88D 0.5° reflectivity (dBZ, per scale) at a) 2103 UTC, b) 2132 UTC, c) 2153 UTC, and d) 2219 UTC 2 May 2007. Approximate beam heights at arrow, respectively, are 6300, 5000, 6000, and 4100 ft (1.9, 1.5, 1.8 and 1.2 km) AGL. Thin grey lines are county boundaries. In (a) and (b), the arrow points toward a supercell that developed on the remnant outflow boundary and that eventually would merge with the bow echo. In (c), the arrow indicates the merger location; and in (d) the arrow points to the embedded bow echo that developed only 20 min after the merger. *Click images to enlarge.*

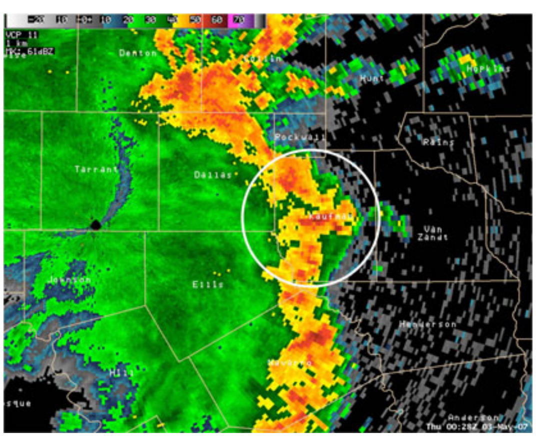
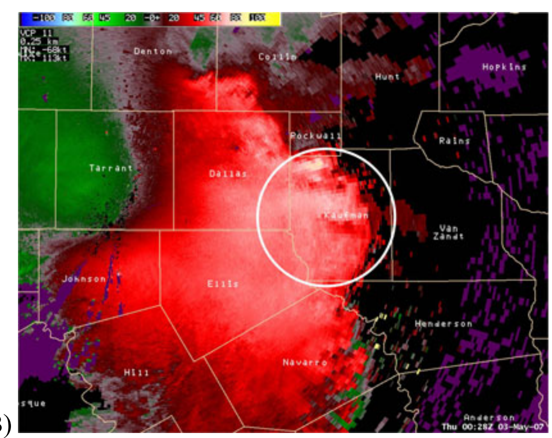
A)  B) 

Figure 14: KFWS WSR-88D 0.5° products depicting BE #2 (circle) over Kaufman County at 0028 UTC 3 May 2007: a) reflectivity (dBZ, per scale), and b) radial base velocity (kt, per scale). Approximate beam height at the center of the circle is 4700 ft (1.4 km) AGL. County names in white, borders are thin tan lines. The embedded bow echo is well defined as a protrusion ahead of the larger bow echo, with two well defined RINs behind the leading edge of convection. The strongest radial velocities on the northern end of the bow echo are associated with a mesovortex. *Click images to enlarge.*

the northern track of the RIN. However, whether this damage was the result of a downburst associated with the bow echo, a mesovortex that moved near the same area, or a combination of both is unknown. An anomalously deep mesovortex (nearly 4.8 km or 15.7 kft), developed north of the apex of BE #1, but may have been the remnants of the mesocyclone after the supercell merger. Damage continued into Hill County, where the storm overturned two trucks on Interstate 35W and blew down hundreds of trees.

Another embedded bow echo (BE #2) developed over northeastern Ellis County and southeastern Dallas County at 0014 UTC. BE #2 became better defined in Kaufman County by 0028 UTC (Fig 14a), with a strong reflectivity protrusion ahead of the larger bow echo and two RINs identified by WECs. The 0.5 degree base velocity image from KFWS indicated an average wind speed of 33–35 m $s^{-1}$ (65–70 kt) with a max speed of 43 m $s^{-1}$ (86 kt) behind the leading edge of BE #2 at 1.2–1.5 km (4–5 kft) AGL (Fig. 14b). Numerous large trees were blown down across the county with the winds near the apex of the bow estimated by spotters to be 39 m $s^{-1}$ (78 kt or 90 mph). In the city of Elmo, the storm knocked down several business signs and heavily damaged the roof to a bank drive-through facility.

*c. Mesovortices*

Two mesovortices were identified along the leading edge of the DCS as it moved across west-central Texas, followed by several more along the leading edge of the bow echo over north Texas. The north Texas mesovortices were sampled well within 60 miles of the KFWS WSR-88D (Table 2). The two west-central Texas mesovortices were located north of the apex of a bow echo, as were all of the mesovortices in north Texas (Atkins et al. 2004). On average, the mesovortices were 3.2 km (10.5 kft) deep, considerably more than the <1 km (3.3 kft) depths suggested by simulations (Weisman and Trapp 2003). The mesovortices were either nearly vertically aligned or tilted slightly upstream and lasted an average of 12 min. The top of each mesovortex was determined subjectively using the volumetric scanning pattern on the WSR-88D. Nearly all of the mesovortices in north Texas occurred south of the intersecting outflow boundary. A feature commonly observed with the mesovortices was a curling pattern in the base reflectivity images (Atkins et al. 2004), with the location of the strongest radial winds in the base velocity data located on the south side of the mesovortex (Przybylinski et al. 2000, Trapp and Weisman 2003). These two radar characteristics made it easier to identify mesovortices in real time.

Table 2: Properties of nine mesovortices identified with the DCS, ordered by depth in km. Mesovortex depths were calculated by subtracting the radar-derived maximum height from base level. The rotational velocity magnitude ($V_r$) was calculated using $V_r = (|V_i|+|V_o|)/2$, where $|V_i|$ and $|V_o|$ are magnitudes of inbound and outbound flow, respectively.

| Mesovortex | Duration (min) | Depth [km(kft)] | Rotational Velocity [m $s^{-1}$ (kt)] |
|---|---|---|---|
| 1 | 19 | 6.0 (19.8) | 20 (38) |
| 2 | 10 | 4.2 (13.9) | 19 (36) |
| 3 | 19 | 3.1 (10.1) | 14 (27) |
| 4 | 10 | 3.0 (9.9) | 18 (35) |
| 5 | 10 | 2.9 (9.4) | 24 (47) |
| 6 | 10 | 2.7 (8.9) | 21 (40) |
| 7 | 10 | 2.5 (8.3) | 19 (36) |
| 8 | 8 | 2.3 (7.5) | 17 (33) |
| 9 | 12 | 2.0 (6.6) | 17 (34) |

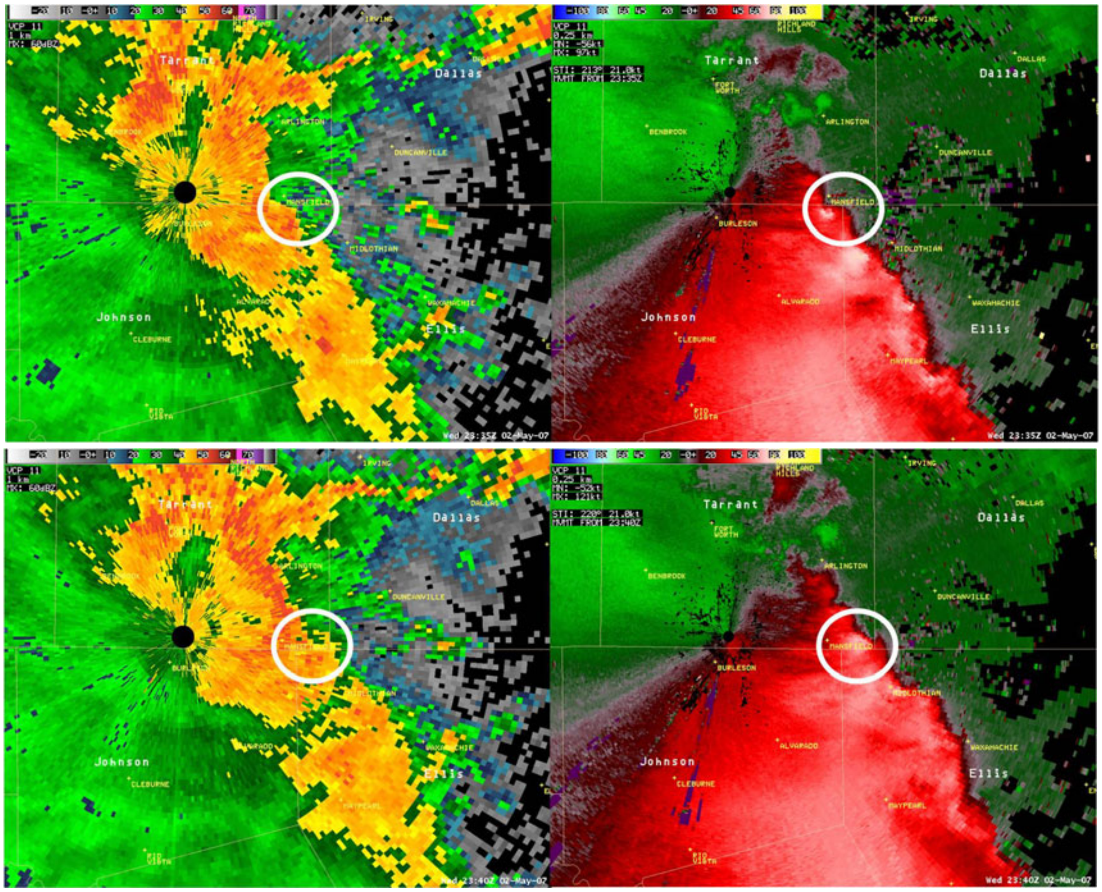
A)
B)



Figure 15: KFWS WSR-88D 0.5° imagery from the Mansfield (Tarrant County) mesovortex (white circle): a) reflectivity and associated storm-relative motion at 2335 UTC; b) as in (a) but at 2340 UTC. Approximate beam heights respectively are 600 and 900 ft (183 and 274 m) AGL at the center of the circle. Mapping conventions and scales as in Fig. 14. *Click images to enlarge.*

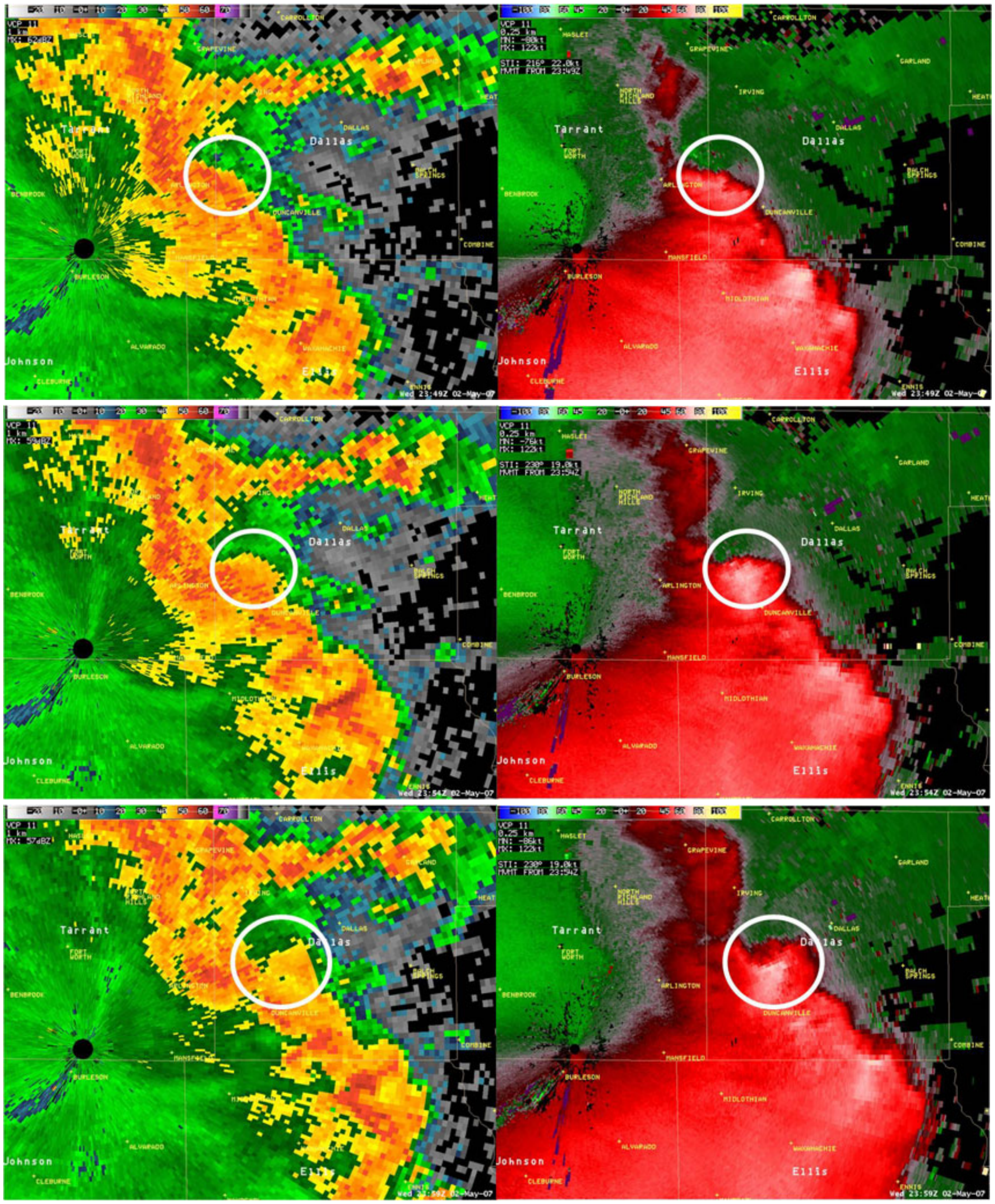
The authors successfully identified wind damage associated with three mesovortices using reports from *Storm Data* (NCDC 2007). Two of the three mesovortices occurred in the Dallas-Fort Worth Metroplex and produced damage suggesting EF1 winds (38–49 $m\ s^{-1}$ or 86–110 mph) (WSEC 2006). Other damage reports may have been caused by mesovortices; but due to discrepancies in report times and radar analysis, the link between these reports and mesovortices could not be achieved confidently.[2]

The first mesovortex occurred in Runnels County (map, Fig. 1) and was sampled best by the KDYX WSR-88D. It developed around 1908 UTC and lasted about 12 min. This mesovortex (#9 in Table 2) was one of the shallowest of the day. Along its path, five telephone poles were knocked down (EF0 damage).

The second mesovortex (#7 in Table 2) developed in extreme northeastern Johnson County at 2335 UTC and moved over Mansfield in southeastern Tarrant County (Fig. 15). Radial velocity from KFWS sampled 38–40 $m\ s^{-1}$ (75–80 kt) at only 0.2 km (0.58 kft) AGL on the southern side of the mesovortex. In southeastern Tarrant County, two construction trailers were blown over, a flagpole was bent 45º, and the roof was torn off a commercial business (EF1 damage).

The third mesovortex (#4 in Table 2) moved through western Dallas County (Fig. 16). The mesovortex was 3 km (9.9 kft) deep and base velocity sampled up to 43–45 $m\ s^{-1}$ (85–90 kt) at approximately 0.44 km (1.40–1.45 kft) AGL,

[2] See Hales and Kelly (1985) for discussion of such report-verification issues.




A)
B)
C)

Figure 16: As in Fig. 15, but for the western Dallas County mesovortex at a) 2349 UTC, b) 2354 UTC and c) 2359 UTC. Approximate beam heights respectively are 1200, 1500, and 1700 ft (366, 457 and 518 m) AGL at the center of the circle. *Click images to enlarge.*

while due east of the radar. On the outer fringes of this mesovortex, a wind gust of 29 m $s^{-1}$ (57 kt) was measured at an automated weather station in Grand Prairie. Collocated with the radial velocity sampling of 43–45 m $s^{-1}$ (85–90 kt), a roof from a two-story apartment building landed across the road. Winds blew another roof off a warehouse and an overhead sign down on a major Interstate, consistent with EF1, possibly EF2, intensity winds.

## 7. Discussion

A derecho on 2 May 2007 resulted in nearly $2.7 million in damage in west-central and north Texas. The DCS underwent several transitions:

(1) a cluster of storms that evolved into a single bow echo, (2) a middle phase consisting of a LEWP with bow echoes and supercells, and finally, (3) a larger bow echo that moved across north Texas. Low-level mesovortices were observed along the leading edge of the north Texas bow echo, and radar analysis suggests some of these were responsible for the most damaging winds in the WFO FWD CWA.

Derechos commonly occur in regimes of weak synoptic forcing and the thermodynamic environment along and ahead of the 2 May 2007 DCS supported derecho development. However, other studies involving numerical simulations have suggested that the weak vertical wind differences observed before and during this event were below guidelines typically associated with the presence of deep mesovortices and elevated RIJs. This case, therefore, is unique because the bow echo was able to support deep mesovortices and an elevated RIJ in weak ambient vertical wind shear. Even though research continues on the development and role of mesovortices, little documentation exists on those occurring in weakly-sheared environments; and more such research is needed. Additional case studies and documentation of similar events also would improve the database for further studies on this topic.

This case provides two examples whereby keen situational awareness can lead to successful short-term forecasts and warnings. The first challenge facing forecasters at WFO FWD on the morning of 2 May 2007 was estimating the likely duration of the DCS. As the DCS moved away from the strongest upper-level support in west Texas, it encountered a more unstable environment that was still favorable for severe weather. This helped to maintain the DCS for nearly 12 h. Recognizing that the convective system had reached maturity (hereby defined as having an elevated RIJ to enhance continuous lifting along the leading edge of the DCS despite weak vertical wind shear), and the fact that the downstream thermodynamic environment supported deep moist convection, helped forecasters to plan successfully for the system's sustenance and movement into the FWD CWA. The damaging wind event in north Texas was forecast with a lead time up to 12 h, even though the DCS arrived earlier than expected.

This case also illustrates that maintaining forecaster awareness during real-time warning operations is crucial. The environment on this day could support severe weather, but deep mesovortices did not appear likely because of the weak vertical wind shear. However, circulations did develop within the quasi-linear convective system, requiring close scrutiny by a radar operator and warning forecaster. A constant predictive challenge is the potential for embedded circulations to produce tornadoes. The tornado risk increases when supercells with mesocyclones are present, but techniques to distinguish between tornadic and non-tornadic low-level mesovortices have yet to be established. In this case, a few tornadoes did occur in west-central Texas in association with supercells, but no tornadoes were reported with any of the low-level mesovortices. On 2 May 2007, warning forecasters issued eight tornado warnings for parts of west-central Texas; three verified with reports. On the other hand, no tornado warnings were issued for north Texas. Warning forecasters were not able to discern a higher tornado potential in this case based just on the depths of the mesovortices. However, warning forecasters need to consider the depth of a low-level mesocyclone and the possibility that the mesovortex could deepen, being ready to enhance the wording in warnings and statements about the threat for greater wind speeds and damage.

ACKNOWLEDGMENTS

The authors would like to thank Dan Miller, Stephen Corfidi, Chris Maiers, and Roger Edwards for their formal comments and reviews of this paper. The authors would also like to thank Greg Patrick, Science and Operations Officer at WFO FWD, for his help in obtaining data, reviewing and editing the paper, and Ted Ryan, a senior forecaster at WFO FWD, for his insights on MCSs and this case.

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## REVIEWER COMMENTS

[Authors' responses in *blue italics.*]

**REVIEWER A (Christopher M. Maiers):**

***Initial Review:***

**Recommendation:** Revisions required.

**Substantive Comments:** The literary review was pretty thorough. I would have liked to have seen some review of the EF-scale in there since there are references made to comparing straight-line wind damage to a tornado damage scale. Some literature to show this precedent is needed to keep the paper in current form. Your synoptic analysis is very good as well.

S-band attenuation is probably not a major factor in the radar data with the exception of the moment the QLCS passes directly over the RDA, but even then it doesn't appear to be significant or even noticeable for more than two volume scans. The down radial cores appear to maintain strength by crude analysis of the displayed reflectivity for most of the event. I've seen cases that have reflectivity values fall once the surging winds really go forward. This may be an instance like that where some of the larger hydrometeors are broken up into smaller parts.

*Good point regarding this case…we have removed this statement from the manuscript.*

Using the EF Scale to me is a bit of a stretch since that appears to be so closely associated with tornadic damage. There are articles that set a precedent of using the F-scale to rate straight-line wind damage in QLCS type events, but that may not be the intended use of the EF-Scale. *[Editor's Note: EF-Scale is intended for all forms of wind damage, not just tornadic.]* Perhaps it would be better semantics to give a range of speeds and leave it at that or use Beaufort Force or even possibly the Saffir-Simpson Scale since those would tend to be more straight-line in nature over a localized area. Another area of caution is that many of the damage indicators in the EF-Scale see their damage caused by a rotating wind over an area in which the stricture may take high 3 second wind gusts from several different angles as opposed to one primary incident angle with straight-line winds.

*The authors agree that the EF-Scale is primarily used for assessing wind damage associated with tornadoes, but we agree with the Editor that the EF-Scale is used for all forms of wind damage. As the EF-Scale documentation states, first the damage indicators are determined and ranked, then a wind speed is assigned, and finally an EF rating is assigned. During their research, the researchers used the first two steps to correlate the wind damage to the EF-Scale. However, per a suggestion from another reviewer, we have modified the manuscript to read "equivalent to EF() intensity", or a similar version of the preceding wording, where appropriate. We also reworded the first paragraph of the "Data and methodology" section to acknowledge that the EF-scale is most commonly used to assess tornado damage but that it can also be used to assess straight-line wind damage.*

*[Text-body block from manuscript omitted…]*

Under the Mesovortices section there is a reference made to mesovortices causing EF-1 damage. Great care must be taken here with this classification so as not to convey this as tornadic damage. It would be more appealing to perhaps list a range of wind speeds and make a loose comparison to the EF-scale instead of a direct reference.

*We have modified the manuscript to read "equivalent to EF() intensity", or a similar version of the preceding wording, where appropriate.*

I feel as though the conclusion is relatively weak compared to the rest of the paper. Your points are there, but there may be something profound to be discovered with environments like this. You have some room to suggest that perhaps a more in-depth study is needed for environments like this to see if there is something along the lines of a smoking gun that can point to these more severe QLCS events across various environments.

*We agree that the original conclusion was weak and at the time were struggling to strengthen it. Hopefully the edited Discussion section is better. In the revised section, we include operational lessons learned and recommendations for similar situations.*

***Second review:***

**Recommendation:** Accept with minor revision.

**Substantive Comments:** The literary review was very thorough as it was last time. This time the reasoning and explanation for using the EF-Scale was properly laid out and explicit. This will cut down on potential confusion any reader might have while reading the damage classifications. Thank you for making those changes.

The authors have put a lot of work into this second submission. Overall the paper quality has improved especially in the area of the Discussion. I would still like to see perhaps a call for more research done on lower-end environments, and since this is one of those cases the authors probably have room to do so. This case may be an outlier in some regards, but more research is needed to prove that it is truly an outlier or just a victim of previous case sampling.

*The following lines have been included in the Discussion section (end of paragraph 2):*
*"More research is needed to better understand the development of deep low-level mesovortices in weak vertical wind shear environments. Additional case studies and documentation of similar events would also immensely improve the available information for further studies on this topic."*

I did not object to any part of the synoptic or radar analysis. The analysis was put forward very well and concisely.

Suggestions for operational handling of the event were good as well.

Based on the improvements to this paper, I see no reason as to not approve of it.

*Thank you very much for your suggestions in both rounds of review and for your acceptance of the paper!*

**REVIEWER B (Stephen F. Corfidi):**

***Initial Review:***

**Reviewer recommendation:** Accept with minor revision.

**General Comments:** This paper discusses the 2 May 2007 northern Texas derecho-producing mesoscale convective system (MCS) and its associated mesovortices. It presents the synoptic and mesoscale environment associated with the event. It also introduces some of the storm-scale features viewed by National Weather Service WSR-88D radars located in Fort Worth/Spinks, Texas (KFWS), and Granger, Texas (KGRK). To my knowledge, no paper to date has focused on this event. It should be of greatest interest to operational meteorologists.

The manuscript generally is well-written and well-organized. I did make numerous minor comments and suggestions (inserted directly in the original manuscript, and sent as a separate file). Most of these address exposition. These suggested changes, I think, will make for an improved presentation.

*Most of the minor suggestions were accepted, but a combination of all minor edits/suggestions from all reviewers regarding the exposition of the paper was incorporated.*

The authors use English units in some instances, and metric units in others. I suggest using metric units throughout, but including wind speeds in English units parenthetically. *[Editor's note: Metric must be used, either in consistent primary form (no English equivalents) or parenthetically after the English. Either way, the usage must be consistent throughout.]*

*Thanks for the catch! All units should now be in Metric units with English units in parenthesis where appropriate.*

The authors note that the derecho MCS evolved in a shear regime not typically associated with deep mesovortices. As such, the paper could serve as a valuable reminder that significant wind events sometimes can evolve within relatively benign shear environments.

The authors should consider extending their review of the event beyond the Fort Worth-Dallas county warning area. As they note, the storms that evolved into the derecho MCS formed in west Texas early in the day. A check of the composite radar imagery for the date shows that those storms, in turn, evolved from severe pre-dawn storms in eastern New Mexico. Considering the unusual time of day for severe weather in eastern New Mexico, and what appears to be the subsequent development of a damaging morning MCS in west Texas, it might be useful to extend the study westward to see if deep mesovortices occurred in that MCS, and whether or not shear was as weak in that area as it was later in the day in north Texas.

If the authors choose to extend their study as suggested above, I would like to see the revised manuscript; otherwise I do not feel the need to see a later version of the manuscript.

*We have expanded the paper to discuss the environment and events in west and west central Texas. Additions have been made to sections 3-6 with minor wording changes elsewhere in the paper. The Thermodynamic section of the paper continues to focus on the environment in north Texas at 2100 UTC since north Texas is where the most significant damage occurred. However, a few additional mesovortices were discovered to have occurred in west central Texas (WFO SJT CWA) and are mentioned in the Radar section. The shear values in west central Texas were similar to the values in north Texas so no major wording changes were needed in the Kinematic section.*

Is it possible that high PW values contributed to the intensity of this event more strongly than DCAPE? Coniglio, et al. 2010 suggest that high PW may have contributed to the 8 May 2009 derecho MCS in Kansas and Missouri, an event where DCAPE was relatively low compared to other derecho MCS environments. In addition to the abnormally high PW, the 8 May high wind event also appeared to be fostered by a very deep elevated mixed layer, and by an unusually broad/strong low-level jet. The paper has been accepted for publication but is not yet available on the AMS' "Early Online Release" site. If you are interested in viewing a copy, let me know and I will forward you one, or send a paper copy (Mike Coniglio is working on the final version of the manuscript). Here is the reference: Coniglio, M. C., S. F. Corfidi, and J. S. Kain, 2010: Environment and early evolution of the 8 May 2009 derecho-producing convective system. *Mon. Wea. Rev*., in press.

*Although the PW values in this event were not as high as those in the 8 May 2009 event, they were above normal values for this time of year, and a comment was added to note this fact.*

*[Minor comments omitted...]*

***Second review:***

**Recommendation:** Accept with minor revision.

*Thank you very much for your suggestions in both rounds of review and for your acceptance of the paper!*

**General Comments:**

The authors did, in a limited manner, extend their discussion to include a review of the 2 May 2007 derecho event beyond the Fort Worth-Dallas county warning area. I think that this makes for a more complete paper, although I believe that room still exists for additional information on the genesis of the event. The authors also have changed the title of the last section to "Discussion," which I think is appropriate. I made numerous changes to the last two paragraphs of that section in an attempt to tighten the presentation. Hopefully I have not changed the intended meaning of the paper. I trust that the EJSSM editor will work with the authors regarding my suggestions in this area.

*Most of the suggestions/changes in the Discussion section were accepted, and we thank Mr. Corfidi for his recommendations in this section. His suggestions greatly enhanced the Discussion section. The only suggestion of his that I chose not to include was near the end of the last paragraph: "In this case it appears that the shallow nature of the vortices in north Texas may have been related to the absence of reported tornadoes." I understand what Mr. Corfidi is saying in this statement and do not think that his statement is incorrect, but I think it would cause some confusion in this instance. If I understand the statement correctly, I think Mr. Corfidi is making a distinction between mesovortices and vortices (i.e. mesocyclones). A main point in this paper is that the mesovortices were deep (not shallow), and I feel that the reference to deeper vortices (i.e. mesocyclones) in this context would cause confusion. I apologize if I am wrong in my interpretation of his suggestion, but still feel that leaving that particular sentence out will avoid confusion.*

My comments/suggestions elsewhere in the manuscript are quite minor, and I do not feel a need to see a later revision of the paper.

*[Minor comments omitted...]*

**REVIEWER C (Daniel J. Miller):**

***Initial Review:***

**Recommendation:** Accept with minor revision.

**Major Comments:**

Overall, this paper is in pretty good shape.

References: All the references check out and none are left "hanging" either in the body of the paper or in the references section. There are a couple of additional references that pertain directly to this work that I would suggest the authors look at, and incorporate if they feel appropriate:

Black, A. W., and W. S. Ashley, 2011: Nontornadic convective wind fatalities in the United States. *Natural Hazards,* **54***,* 355-366.

Miller, D. J., and R. H. Johns, 2000: A Detailed Look at Extreme Wind Damage in Derecho Events. *Preprints, 20th Conf. on Severe Local Storms*, Orlando, FL, Amer. Meteor. Soc., 52-55.

Miller, D. J., D. L. Andra Jr., J. S. Evans, and R. H. Johns, 2002: Observations of the 27 May 2001 High-End Derecho Event in Oklahoma. *Preprints, 21st Conf. on Severe Local Storms*, San Antonio, Texas, Amer. Meteor. Soc.

*We thank Mr. Miller for the additional references, but chose not to include them at this time. The Miller papers were interesting to read, but we felt there were enough differences between the events. The work by Miller focuses on extreme damaging wind associated with supercells embedded within the DCS, causing* *long swaths of high-end damage. Supercells are usually associated with much deeper mesocyclones that are different from the deep mesovortices focused on in this paper. While the DCS was moving through west central Texas, there were a few supercells present, but very few reports of non-tornadic damaging winds were reported in association with the supercells and the damage was usually confined to a single point; at least according to Storm Data publication.*

A derecho is defined as the wind event produced by an MCS, therefore, the correct scientific terminology is derecho-producing mesoscale convective system (DPMCS) – suggest putting this out there right at the start – it make using DPMCS thru the rest of the paper really easy!

*We have edited the text to read "derecho-producing mesoscale convective system" but prefer to leave the acronym as DCS. This acronym is more commonly used in literature, and the authors have yet to see the acronym "DPMCS" used in literature. The authors also polled fellow colleagues and forecasters, and it was agreed that the term DCS was more commonly known and accepted, therefore we feel more comfortable using the acronym "DCS".*

In reading [Section 4], I guess I'd like to see more data that explicitly shows where the large scale and mesoscale forcing for this event were located. It's easy to infer things from water vapor satellite imagery and streamlines, but I've seen many, many instances where this leads one down the wrong diagnostic path. For large scale forcing, I'd like to see some plots of q-vectors in the 850-300mb layer (synoptic purists would argue to use 500-300mb to minimized the effect of fronts, but ultimately 850-300 mb usually provides a decent first guess since one ultimately detach the effects of low level forcing from WAA/fgen [frontogenesis]). In addition, I think it is necessary to include some images or a loop of 925-850mb temp/wind/thermal advection/moisture transport/fgen – ultimately updrafts are forced in the lower levels of the atmosphere, and these plots should do a much better job of explicitly showing where the mesoscale low level forcing existed. There is a LOT of inferred/assumed phraseology in the following paragraphs—i.e. "but the strongest WAA remained south of the track of the DPMCS DCS and likely did not contribute to large scale ascent along its path", and I'd like to see some evidence to support those claims.

*Figures 4 and 5 have been added to the paper. Figure 4 displays q-vector divergence in the 850–300-mb level at 4 different times during the event, and Figure 5 displays q-vector divergence in the 850–700-mb level at 4 different times during the event. These images were originally left out to limit the number of figures in the paper, but have been added per your request.*

*The authors did analyze frontogenesis in the lower levels of the atmosphere, but the signal was weak and the q-vector divergence image in the 850-700 mb layer better displayed the low-level lift across south and central Texas.*

[Section 4 Re: Comparisons to Evans/Doswell classifications…] Re-word or just leave out. I don't think it's of paramount importance that this (or any other event) "fit" into a preconceived notion of evolution—if it doesn't exactly fit, it's okay to say that.

*The authors understand the reviewer's approach on this suggestion, and this sentence has been re-worded slightly to better the flow of the paragraph. The authors prefer to keep the comparisons for similarity/disagreement purposes; it's a major component of the paper. Therefore we limit the comparison to E&D's weak forcing environment.*

[Section 5] General comment regarding the use of DCAPE in forecasting cold pool strength in MCSs: While I realize that the use of DCAPE has become more common and that several publications/indices use it (i.e., Evans and Doswell and the SPC meso-analysis page), I'd like to propose that this may be more of a non-proven associative phenomena with MCS/cold pool strength. An MCS is processing air parcels from hundreds of kilometers around it, both in the convective updrafts, and entrainment of mid level environmental air from the system-relative rear. It is this rearward entrainment of air and interaction with the precipitation cascade that is largely responsible for the cold pool generation and maintenance over time. Thus, a logical question follows: why would a measurement of DCAPE at a point forecast sounding site ahead of the MCS be an accurate and representative measure of 1) DCAPE and 2) subsequent cold pool strength?

*A statement was added in this section to qualify the use of DCAPE as an estimate which is dependent on the origin of the parcels in the MCS downdraft.*

*[Text-body block from manuscript omitted…]*

*[Minor comments omitted...]*

***Second review:***

**Recommendation:** Accept with minor revision.

**General Comments:** I'm perfectly fine with leaving those references out if that's what the authors' best judgment is. The only reason I suggested perhaps mentioning them is that the wind event produced by this DCS seemed to have at least some characteristics of XDW events. It turns out that the XDW events examined in Miller and Johns and Miller et al were all associated with supercells (or structures that in essence resembled supercells in 4D radar evolution), but those papers didn't go so far as to say that all XDW events were associated with embedded supercell elements. In fact, the first paper made note to mention at least 2 XDW events that seemingly were produced by more "classic" bow echo radar structure. I saw this as simply an opportunity to document a quasi-XDW event as another that didn't necessarily fit the supercell paradigm in the literature, for future reference.

[Re: DCAPE discussion] This section still gives me some heartburn, but the reword and approach is much improved from the first draft. I guess I would still contend that the statement above from E&D makes my point for me regarding the operational use of DCAPE—"potential for cold pool strength, ***dependent upon the origins* of the downdraft parcels in the MCS**" **—**this also does not take into account the precipitation cascade and hydrometeor phase/size distribution therein (which is inherent in the "dependent upon the origins" statement). Basically, I would contend that DCAPE is a much more effective tool for air mass thunderstorms, rather than a mature MCS, especially after upscale growth has occurred (as in the 2 May case during time of study here)

However, I do understand the authors' stance that they would like to stick more strictly to what is already in the literature, rather than attempt to take on that debate in this paper. That is perfectly acceptable to me, leaving the broader topic of application of DCAPE and MCS cold pool generation/strength for another time.

*Since the reviewer is okay with the added statement, we do not wish to include any further information or discussion on this topic. As the reviewer stated, this could begin an entirely new debate, and we wish to keep the focus for this paper primarily on the mesovortices.*

*[Minor comments omitted...]*

Other than [omitted minor comments], my recommendation is to accept for publication as-is. Good job to the authors on an excellent case study and well-written manuscript.

*Thank you very much for your suggestions in both rounds of review and for your acceptance of the paper!*