The 1 June 2004 North Texas Derecho: A Case Study

Abstract

A case study of the 1 June 2004 storms that produced damaging winds across north Texas and Louisiana is presented. The synoptic and mesoscale environment is analyzed with emphasis on operational forecast parameters. Northwesterly flow aloft and strong instability produced a favorable environment for a linear mesoscale convective system (MCS). Storm evolution is analyzed from initiation through MCS organization using archived data from the Weather Event Simulator (WES). Although surface boundaries played an important role in storm initiation, the storms moved away from those boundaries and were not dependent on them to sustain convection. Early in the episode, right and left supercell splits were observed. Two supercells in close proximity to each other developed intense outflow winds and then merged with new convection to form a forward-propagating MCS. In this case, individual supercells played an important role in the event, producing some of the most damaging winds. The intense winds produced damage to trees, buildings, and power lines over a wide swath more than 400 km long and 100 km wide.

1. Introduction

Forecasting damaging straight line wind events is important because these storms account for a significant amount of property damage and casualties. A recent study that compared derechos to hurricanes and tornadoes during the period of 1986-2003 concluded that derechos can be similar to most United States tornadoes and hurricanes in terms of their threat to life and property (Ashley and Mote 2005). One such storm event affected the Dallas-Ft. Worth Metroplex and the region to its east during the evening and overnight hours of 1-2 June 2004. The winds produced by this powerful storm complex qualify it as a derecho by the Johns and Hirt definition (Johns and Hirt, 1987). This event left over 500,000 customers without electric power, injured two people in a mobile home, and caused extensive damage to buildings and trees.

Like many derecho events in north Texas, this one occurred in the late spring in a northwesterly upper level flow regime. At least four similar events have been recorded in north Texas since 1989 including 4 May 1989, 27 May 1990, 29 May 1994 (Bentley and Mote, 1998) and 27 May 2001 (Miller et al., 2002.) Using modified derecho criteria, Bentley found that southern Great Plains derechos represent 16% of the total springtime derechos in the central and eastern United States (Bentley and Mote, 1998). Their criteria omitted the necessity for three reports of F1 damage or three reports of 33 m sec^{-1} wind and used ground reports instead of radar to establish event continuity. Other climatological studies have shown that MCSs often occur on successive days under similar conditions (Parker and Johnson, 2000; Ashley et al., 2004). For the 1 June 2004 event, linear MCSs were observed in the same region during the previous and following days.

2. Data and Methods

Archived radar, surface observations, soundings, and model output data from the National Weather Service Weather Forecast Office (WFO) in Ft. Worth, TX were displayed on a Weather Event Simulator (WES) for this study. The KFWS WSR 88D radar images including base reflectivity, storm relative motion, and radial velocity were used. Regional surface observations, GOES IR satellite images, national radar mosaics, upper air analyses, and soundings were also taken from the Storm Prediction Center (SPC) Severe Thunderstorm Events archive. Storm reports were taken from the Ft. Worth- WFO Severe Weather Log (Ft. Worth County Warning Area), and the Storm Prediction Center Storm Reports database.

3. Synoptic and Mesoscale Analyses

Synoptic Scale Evolution

A broad upper level trough had moved into the central Plains on 29 May 2004 and aided in the development of severe weather, including tornadoes, across parts of Oklahoma, Kansas, and Nebraska. As an associated surface low over the northern plains moved slowly north- northeast over the following two days, a trailing cold front moved south into north Texas before becoming quasi- stationary by the evening of 31 May (**Fig**. **1**).

By the morning of 1 June 2004, the broad 500 mb trough had moved northeast and was situated over the Great Lakes region (**Fig. 2**). Northwesterly flow aloft characterized by 500 mb wind speeds of 35 knots was established over north Texas. A 700 mb short wave trough over southwest Kansas and the northwestern Texas panhandle was rotating through the northwest flow and was poised to move southeastward toward north Texas (**Fig. 3**). The front that had become quasi- stationary, was lifting northward across North Texas in response to the approaching upper level short wave trough.

Mesoscale Analysis

The position of surface boundaries played a key role in storm initiation. During the morning hours of 1 June 2004, the diffuse surface front lifted north, and at 1800 UTC, surface dewpoints of 70° F appeared as far north as the Dallas-Ft. Worth area. A thermally-induced surface low in northwest Texas deepened in response to the approaching short wave, and at 2000 UTC, a well-defined dryline extended from near Childress, TX to near San Angelo, TX. Dewpoint gradient across the dryline was sharp, with a 2000 UTC surface dewpoint of 45°F reported at Abilene, TX and a surface dewpoint of 73°F at Mineral Wells, TX. A dryline-front intersection was situated in northwest Texas near Wichita Falls, with the front extending east-northeastward through southern Oklahoma (**Fig. 4**). West of the dryline, a thermal axis extended through Abilene with surface temperatures >100°F. In the warm sector, there were significant variations in surface dewpoints, perhaps due to vertical mixing.

By late afternoon, thermodynamic parameters at Ft. Worth, TX (KFWD) were favorable for strong convection and a convectively-induced wind event. Clear skies and diabatic heating pushed surface based CAPE values to near 4000 J kg^{-1} and lifted indices to -12°C. A dry elevated mixed layer (EML) with lapse rates near dry adiabatic above 750 mb was evident in the 0000 UTC 2 June 2004 KFWD sounding (**Fig. 5**). The dry EML helped increase downdraft convective available potential energy (DCAPE) to 1171 J kg^{-1}. A relatively high lifted condensation level (LCL) of 4500 ft (1.4 km) AGL and steep low-level lapse rates were also supportive of strong downdrafts.

The thermodynamic parameters from this case were compared to those of other derechos. Evans and Doswell (2001) studied proximity soundings associated with sixty-seven derechos, and plotted CAPE and DCAPE for events that they defined as strong forcing, weak forcing, and hybrid. The 1 June event fits well within the parameter space noted in the Evans and Doswell (2001) study of derechos associated with weak forcing. The MLCAPE on the 0000 UTC 2 June KFWD sounding was 4999 J kg^{-1}, which is well above the 75th percentile of the weak forcing cases (**Table 1**). The downdraft convective available potential energy (DCAPE) of 1171 J kg^{-1} falls above the 50th percentile in their study.
Some kinematic parameters were also compared with Evans and Doswell (2001) for weak forcing derecho cases (**Table 1**). The 0000 UTC 2 June KFWD sounding gave a 0-2 km shear value of 10 m s^{-1}, which fell within the 25th to 75th percentile values of 7.0-12.0 m s^{-1}. The 0-6 km shear value for KFWD was above the 75th percentile for weak forcing cases at 23 m s^{-1}, and at that level, was also supportive of supercells. Other kinematic parameters were also important, including system-relative winds (SRW). Evans and Doswell (2001) found that weak mid-level SRW and strong low-level SRW are associated with weak forcing cases. Although we did not calculate SRW, the 35 knot northwesterly winds at 500 mb and 10 knot southeasterly winds at the surface clearly favored weak SRW aloft and strong SRW at the surface for storms moving in a southeasterly direction.

Surface convergence near the front and dryline probably provided the lifting mechanism for storm initiation. There was evidence of cumulus along the dryline southwest of Dallas-Ft. Worth and to the northwest near the dryline-front intersection as early as 2015 UTC on the satellite image (**Fig. 6**). A capping inversion with a convective temperature of 99° F and CIN of -79 J kg^{-1} was present on the 0000 UTC 2 June KFWD skew T-log P diagram. This inversion suppressed deep convection over much of north Texas, contributing to the strong instability. Some weakening of the capping inversion may have occurred as a result of large scale ascent associated with the approach of the upper level shortwave trough in addition to boundary layer heating which helped parcels breach the cap by late afternoon. Although there is some evidence of an association between the timing of the short wave trough and the onset of deep moist convection, we are careful here to distinguish between the large scale and mesoscale processes (Doswell, 1987.) We believe that the acceleration of the surface wind field between 1800 UTC and 2000 UTC 1 June is also an important effect of the short wave trough which increased warm air advection and convergence near the dryline and dryline-front intersection. The timing of these features was also well phased with the diurnal heat cycle.

4. Wind Reports and Damage

This event originated northwest of the Dallas-Ft. Worth area in the form of discrete supercells, producing extensive wind damage and then organized into a linear MCS that swept across much of east Texas and western Louisiana (**Fig. 7**). Damage was widespread, especially to trees and power lines (**Fig. 8**). The Johns and Hirt definition (Johns and Hirt, 1987) of a derecho requires a concentrated area of convectively-induced winds greater than 50 knots (25 m sec^{-1}) with a major axis length of at least 400 km. The reports must show a pattern and at least 3 reports of gusts greater than 64 kt (33 m sec^{-1}) separated by at least 64 km. No more than 3 hours can elapse between successive wind damage events.

Although our focus is concentrated on significant wind reports across north and east Texas, it is recognized that the event also produced large hail, especially during its early stage, and there were two reports of brief tornado touchdowns in Tarrant County, which are discussed later. Although wind and damage reports (**Table 2**) from this event were numerous in the Ft. Worth County Warning Area (CWA), we have relied primarily on measured wind reports to substantiate the intensity. This is an attempt to avoid errors associated with estimated wind and damage reports (Trapp et al., 2004.)

The majority of severe weather from this event occurred from north Texas to western Louisiana during an eight hour time frame, but the geographic and temporal scale were much larger. We have focused on that time period during which most of the severe weather occurred, but this single convective event can be traced from initiation in northwest Texas around 2200 UTC 1 June to its final decay over southern Georgia around 2200 UTC 2 June, a distance of over 1400 km.

5. Supercell Stage

The association of supercells with damaging winds in derecho cases has been well documented (Miller and Johns, 2000). We identified three supercells that were associated with the derecho-producing MCS. **Fig. 9** shows the motion of these storms in schematic form from 2233 to 0032 UTC 1-2 June 2004, all of which affected north Texas with severe weather. Base reflectivity images indicate that all three storms split into right and left-moving cells (**Fig 10**). We have numbered the storms 1, 2, and 3 from south to north and distinguished the right and left-moving members of each (RM and LM).

Although the reason for the storm splits and sustained left-moving supercell from Storm 1 is not completely clear, the unidirectional wind profile above 700 mb was at least partially in agreement with the supportive parameters defined in Bunkers (2002) (**Fig. 11**). For the left-moving member of Storm 1, an anticyclonic circulation was verified on the storm-relative velocity image. The effect of this left-mover on the other supercells and the organization of the MCS are also unclear, but it did contribute to the severe weather event as a whole through the production of large hail. Large hail (≥ 1.9 cm) production in left-moving supercells is well recognized (Bunkers, 2002.) The left-moving cell from Storm 1 produced 1.75 in (4.4 cm) diameter hail in two counties over a 1 hour time period.

By contrast, Storms 2 and 3 initiated over Clay County northwest of Dallas-Ft.Worth, and their right-moving members moved southeastward. Evidence of mesocyclones appeared on storm-relative velocity images for both storms. A velocity couplet appeared on the storm relative velocity image for Storm 2 at an altitude of about 6000 ft (1.8 km) at 2334 UTC and then disappeared within about 15 min. At 0019 UTC 2 June, a second velocity couplet appeared on Storm 2, and a strong couplet can also be seen on Storm 3 (**Fig. 12**). The reappearance of mesocyclone activity in Storm 2 suggests a cyclic supercell. Spotters photographed Storm 2, which showed a flared base and striations indicative of storm scale rotation (**Fig. 13**). Although there was evidence of mid-level rotation on radar, no tornado reports were received during this time period. Storm 2 produced hail up to 2.75 in (7.0 cm).

Storm 3 followed a path similar to Storm 2, with a centerline about 50 km west. Sufficient separation and low-level inflow were maintained in spite of the close proximity and strong outflow from Storm 2. At 0100 UTC, surface inflow winds at Granbury, TX were 15 knots (8 m sec^{-1}) gusting to 21 knots (11 m sec^{-1}) with a temperature of 84°F and a dewpoint of 73°F. Parts of northern Parker County received heavy rains from both storms, and flash flooding of low water crossings was reported later at 0240 UTC. Storm 3 also produced large, damaging hail, with one report of 2.75 inch (7.0 cm) and another of 4.5 inch (11.4 cm) diameter.

6. Supercell to MCS Transition

Although the HP to bow echo evolution is common, neither storm showed a pronounced bowing structure on radar base reflectivity (Moller et al., 1990) after the onset of high winds. Storms 2 and 3 maintained distinct precipitation cores until at least 0209 UTC 2 June (**Fig.14**). In addition to distinct cores, the 0.5 ° base reflectivity loop in **Fig. 14** shows one or more hook echoes on Storm 2 indicative of continuing updraft rotation. The sustained, distinct reflectivity cores, along with the cyclic mesocyclone activity, suggest that these storms may have been cyclic HP supercells.

The first spotter report of 61 knot (31 m sec^{-1}) winds associated with Storm 2 was reported at 0105 UTC. About 30 min earlier at 0039 UTC, evidence of a broadening inbound velocity signature was seen on the storm relative velocity image of Storm 2 (**Fig. 15**). As time progressed, this area of strong inbound velocity increased in size. A wind speed of 93 knots (42 m sec^{-1}) at 1200 ft (0.4 km) AGL was captured on the base velocity image at 0114 UTC in eastern Parker County (**Fig. 16**). A corresponding wind damage report in Parker County at 0110 UTC showed damage to 20 homes, with trees and power lines down. At the same time strong outflow developed at low levels, a strong rear inflow jet can be seen on storm relative velocity images at higher levels in the storm (**Fig. 17**).

At 0203 UTC, the high winds of Storm 2 had reached south into northern Tarrant County and a wind gust of 75 knots (38 m sec^{-1}) was recorded at Meacham Field in north Ft. Worth. Two reports of brief tornado touchdowns were reported shortly after 0200 UTC, but lacking damage and evidence of circulations on radar, it was not possible to verify the events. By 0204 UTC, Storm 3 had also begun to produce strong outflow winds in Parker County. With its gust front now merging with Storm 2, Storm 3 continued southeast into Johnson County where it destroyed a mobile home, injuring two people.

At 0124 UTC, some expansion of the developing MCS was evident on the northeast side of Storm 2 where a new cell had formed in southwest

Denton County (**Fig. 18**). This new cell moved southeastward into Dallas County and produced 65 knot (34 m sec^{-1}) winds at Dallas Love Field. It continued southeastward and produced more damage and high wind reports in southeast Dallas and Kaufman Counties. Yet another cell formed farther northeast in eastern Collin/western Hunt Counties. This storm moved east into Hunt County, producing damage and a 39 knot (20 m sec^{-1}) wind gust at Greenville Majors Field.

The formation of new storm cells on the northeast flank of Storm 2 was investigated further. These cells appeared to form along a cold pool boundary, or perhaps a low-level theta-e axis. The surface pressure at McKinney (TKI) in Collin County increased from 1005.3 to 1010.2 mb over a 2 hour period, which may have indicated the development of a meso high from nearby storms. The surface theta-e contours show an expansion of an area of lower theta-e values toward the southeast, possibly indicative of a cold pool at the surface resulting from the collapse of the left-moving member of Storm 1 (**Fig. 19** and **Fig. 20**). The new storms appeared to form on the southeast edge of the low-level theta-e gradient or cold pool.

As the system consolidated into a linear MCS, the storm reports progressed from damaging hail to damaging winds (**Fig. 21**). By about 0300 UTC, the four distinct cells had consolidated into a more or less continuous line with evidence of at least one rear inflow jet (**Fig. 22**). There is also evidence of strong convergence along the line (**Fig. 23**). Between 0300 and 0500 UTC, the line shifted from its east-west orientation to a more north-south orientation as the stronger cells on the southern flank accelerated rapidly eastward. The KFWD 0-6 km mean wind at 0000 UTC 2 June was 231° at 11 knots (5 m sec^{-1}), but forward motion was greater than 25 knots (11 m sec^{-1}). Corfidi (1998) showed that system motion is in the direction of greatest system-relative convergence for environments similar to this one.

8. Conclusions

A synoptic scale pattern characterized by northwesterly flow aloft, surface boundaries, high instability, dry air aloft, and modest shear, produced a derecho event that evolved from discrete supercells to a linear MCS over a period of about four hours and produced severe weather for approximately eight hours. A high LCL, dry air aloft, and modest mid-level winds probably favored strong thunderstorm outflow and may have prevented tornadic thunderstorms. The strongest winds and largest hail occurred during about the first five hours after storm initiation when two HP supercells produced intense outflow winds. Radar images captured a rear inflow jet in the mid-levels of the storms. Storm motion during the supercell stage varied widely, as splitting supercells gave way to dominant

HP supercells that moved southeastward. The transition to a linear MCS was marked by the northeastward expansion and formation of new cells along a surface cold pool and low-level theta-e gradient.

The impact of this event on society was significant. In this case, widespread damaging winds produced considerable damage to power lines and property, totaling over $100,000,000 in Tarrant County alone. This event also produced two injuries when a mobile home was destroyed. Beyond the threats for hail, high winds, and tornadoes, it also produced flash flooding from heavy rains, and brought precipitation to a 1000 km swath across the northern Gulf States over the following day. The effects of this event were clearly significant to forecasting over a large region.

9. Acknowledgements

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Figure Captions

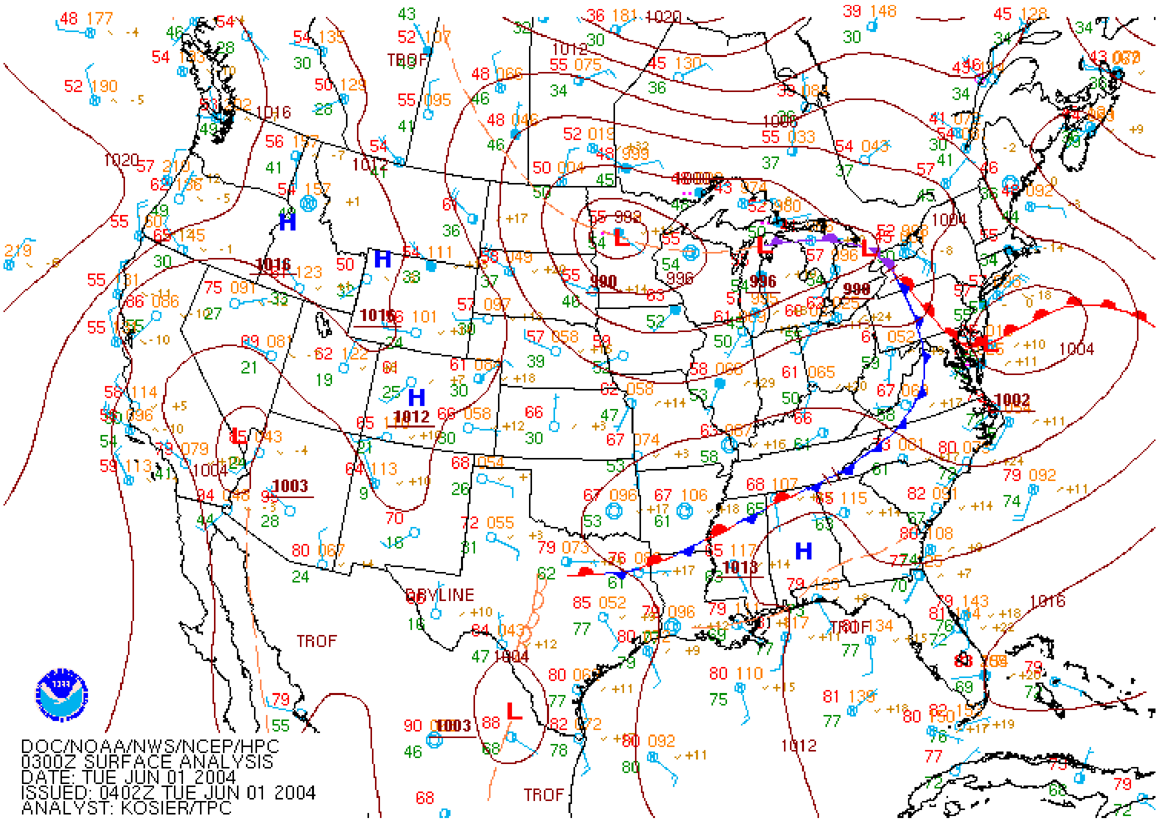

Fig. 1 Surface analysis for the evening of 31 May 2004 (0300 UTC 1 June) showing the quasi-stationary front position in Texas. (Courtesy of NOAA/NWS/HPC).

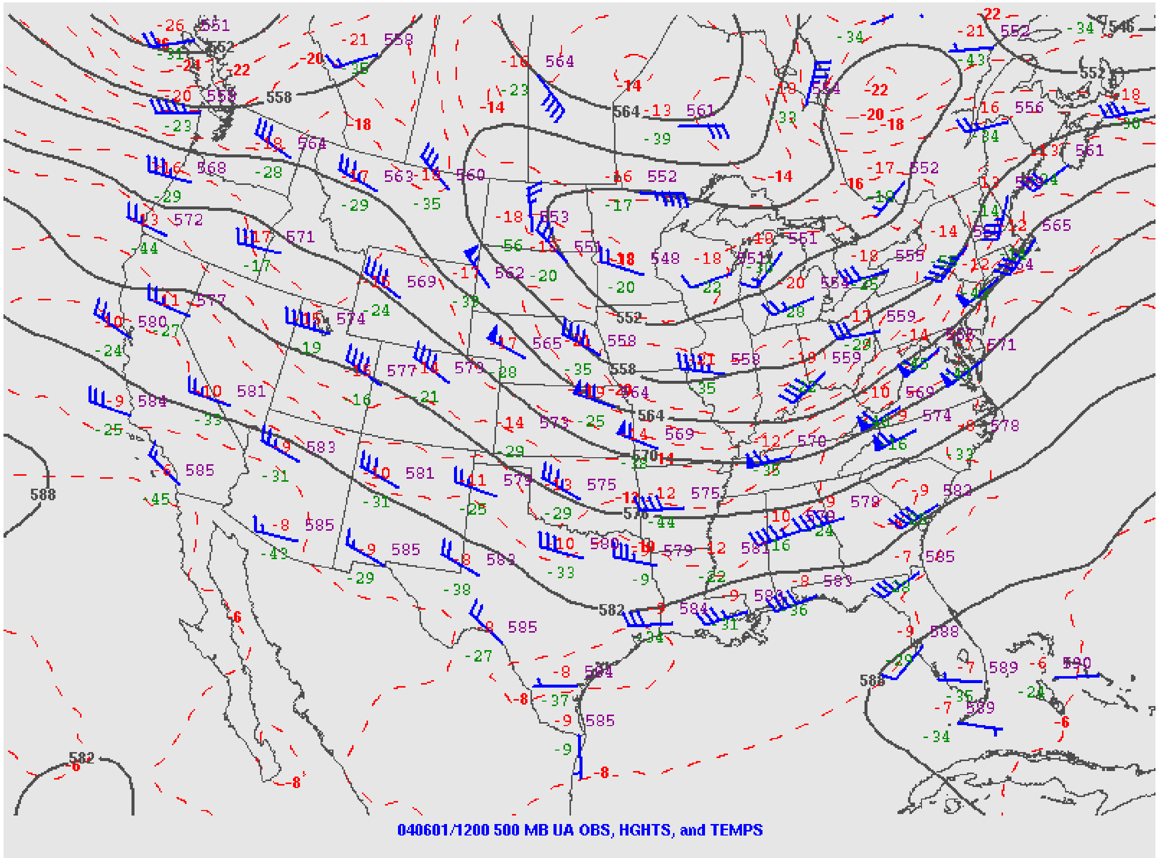

Fig. 2 500 mb height and temperature objective analysis for 1200 UTC 1 June 2004 showing northwesterly flow and a thermal trough over northwest Texas. Solid lines denote 500 mb geopotential heights (dm) and dashed red lines denote 500 mb temperatures (°C). A broad center of low pressure can be seen over the Great Lakes region and northwesterly flow over north Texas. (Courtesy of NOAA/NWS/Storm Prediction Center).

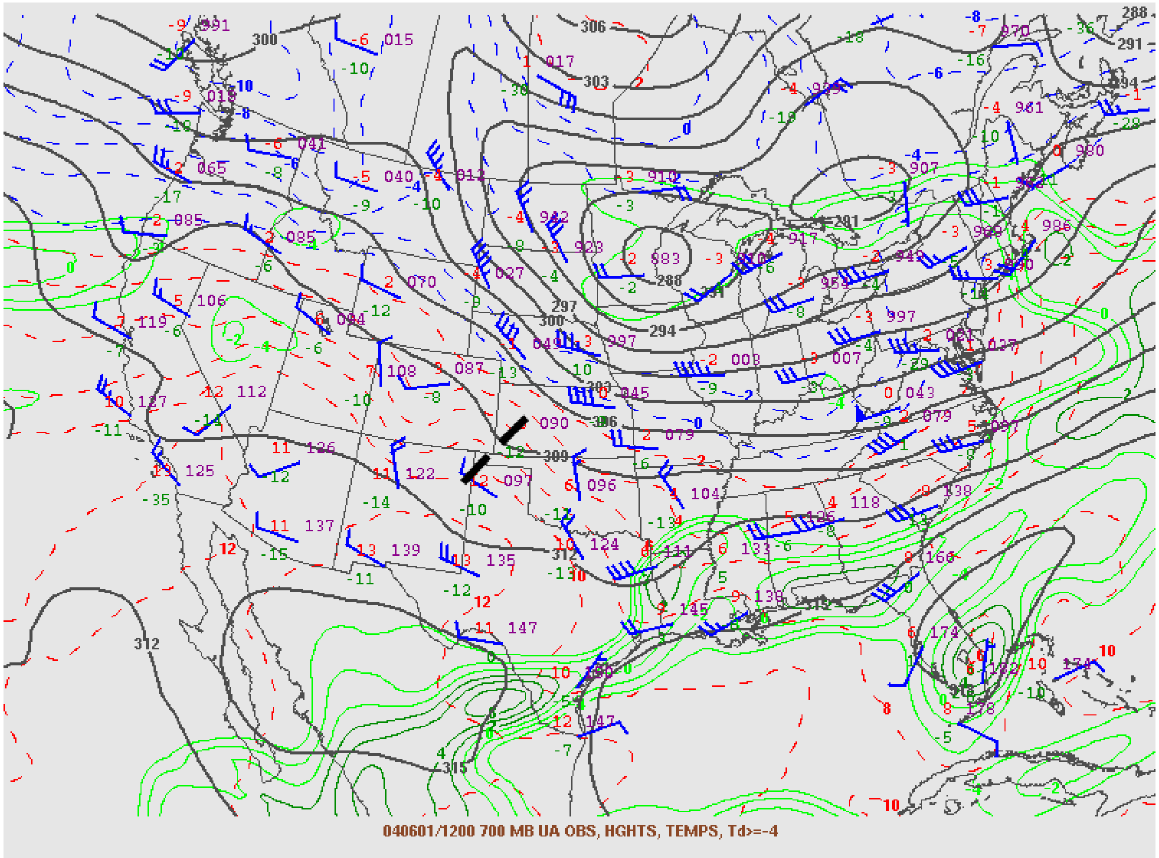

Fig. 3 700 mb height and temperature objective analysis for 1200 UTC 1 June 2004 showing a shortwave trough over southwestern Kansas and the northwestern Texas panhandle denoted by heavy black lines. Solid lines denote 700 mb geopotential heights (dm) and dashed red lines denote 500 mb temperatures (°C). (Courtesy of NOAA/NWS/Storm Prediction Center).

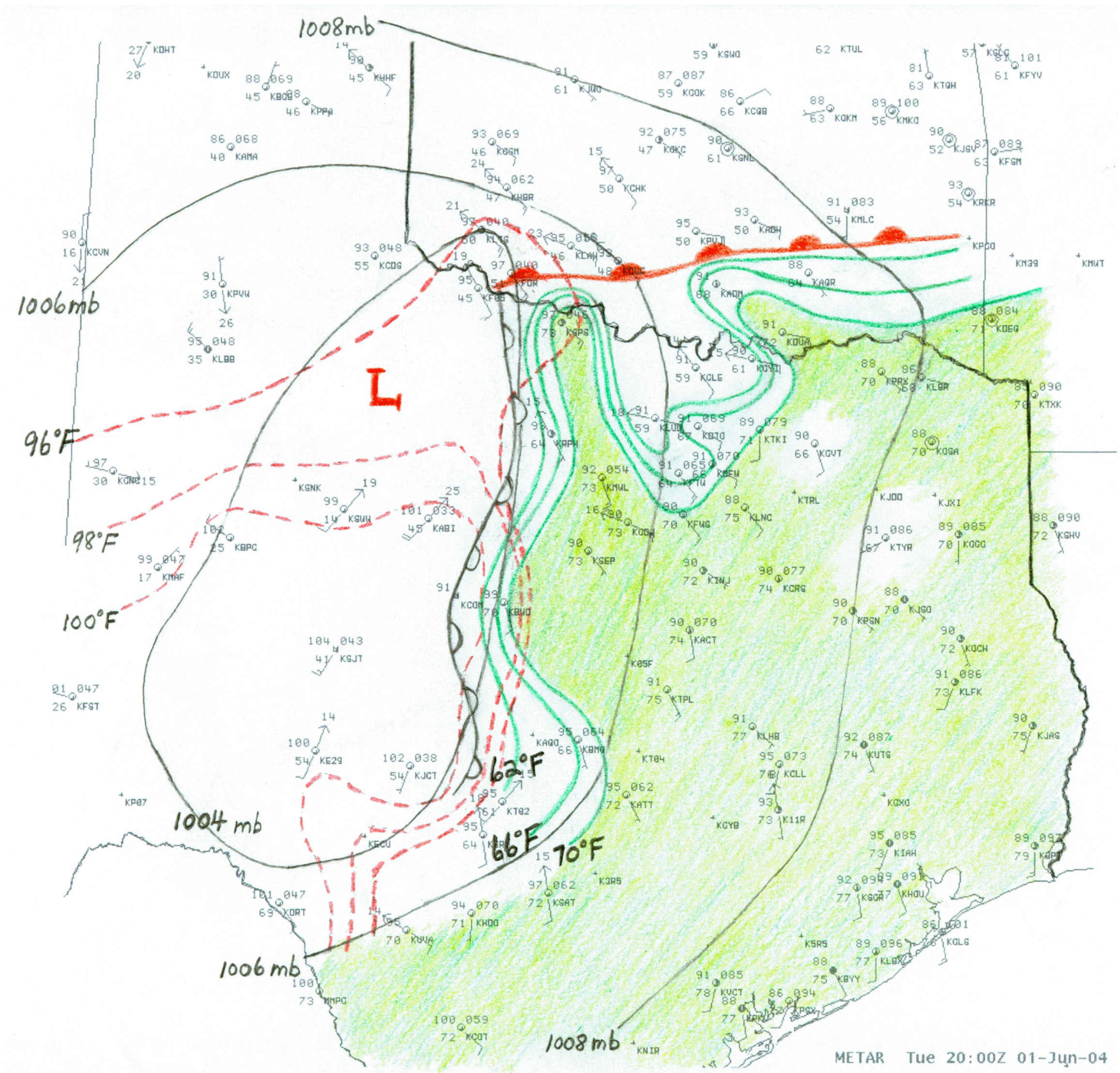

Fig. 4 Surface analysis at 2000 UTC 1 June 2004. The 62- 70°F isodrosotherms are shown in green. The area of dewpoint temperatures >70°F is shaded in green. Note the moist axis extending north along the dryline. Isobars are denoted by solid black lines. A thermally- induced low is positioned over west Texas. The 96- 100°F isotherms are represented by the dotted red lines.

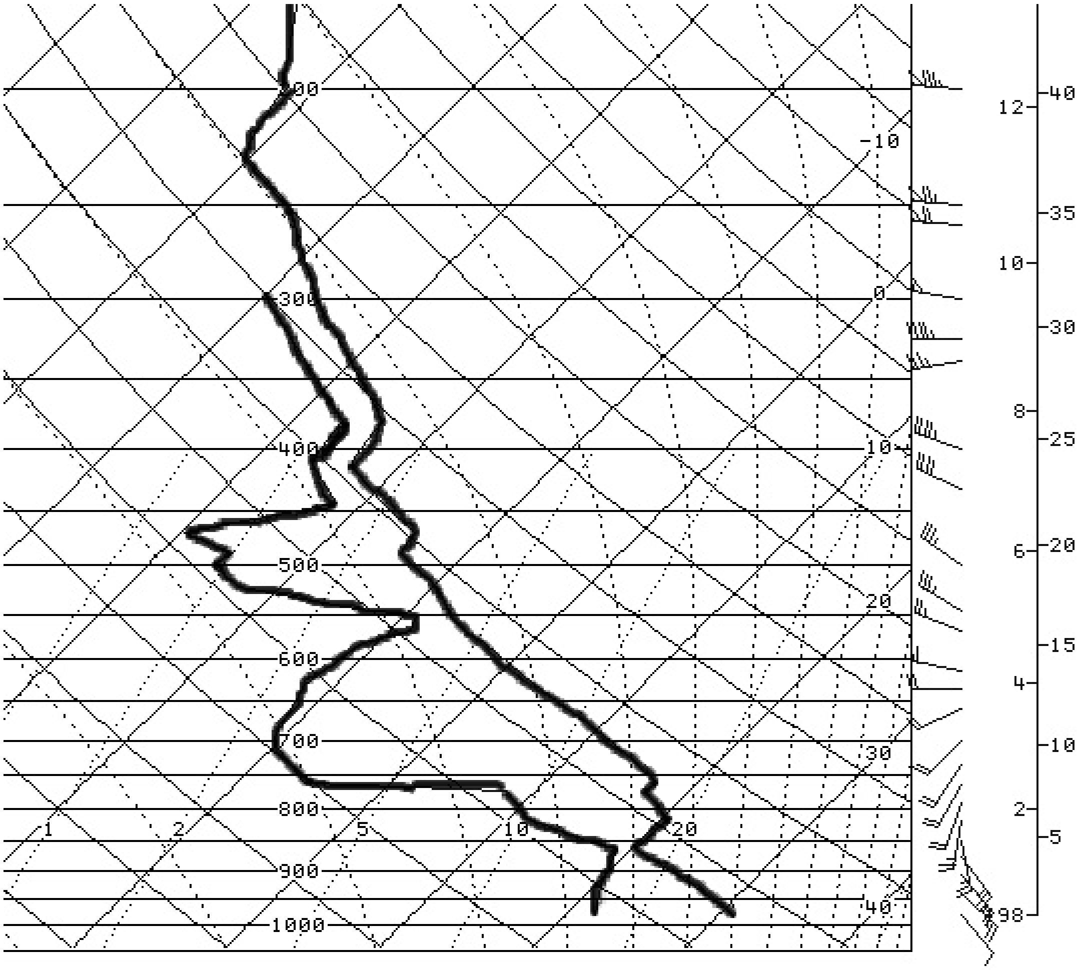

Fig. 5 The KFWD (Ft. Worth, TX) log p- skew T analysis for 0000 UTC 2 June 2004. The temperature plot shows steep lapse rates between 750 and 500 mb and a capping inversion at about 800 mb. Note the dry elevated mixed layer (EML) above about 750 mb.

Comparison of Parameters

Parameter	02 June 2004 0000 UTC	Evans-Doswell 2001*
MLCAPE (J kg^{-1})	4999	1578-2924
DCAPE (J kg^{-1})	1171	968-1352
0-2 km shear (m s^{-1})	10	7.0-12.0
0-6 km shear (m s^{-1})	23	10.5-20.0

*25th - 75th percentile for weak forcing (WF) cases

Table 1 A comparison of sounding parameters for KFWD (Ft. Worth, TX) and the parameter ranges reported by Evans and Doswell (2001) for weak forcing cases. Note the high mixed layer CAPE (MLCAPE) for 0000 UTC 2 June 2004.

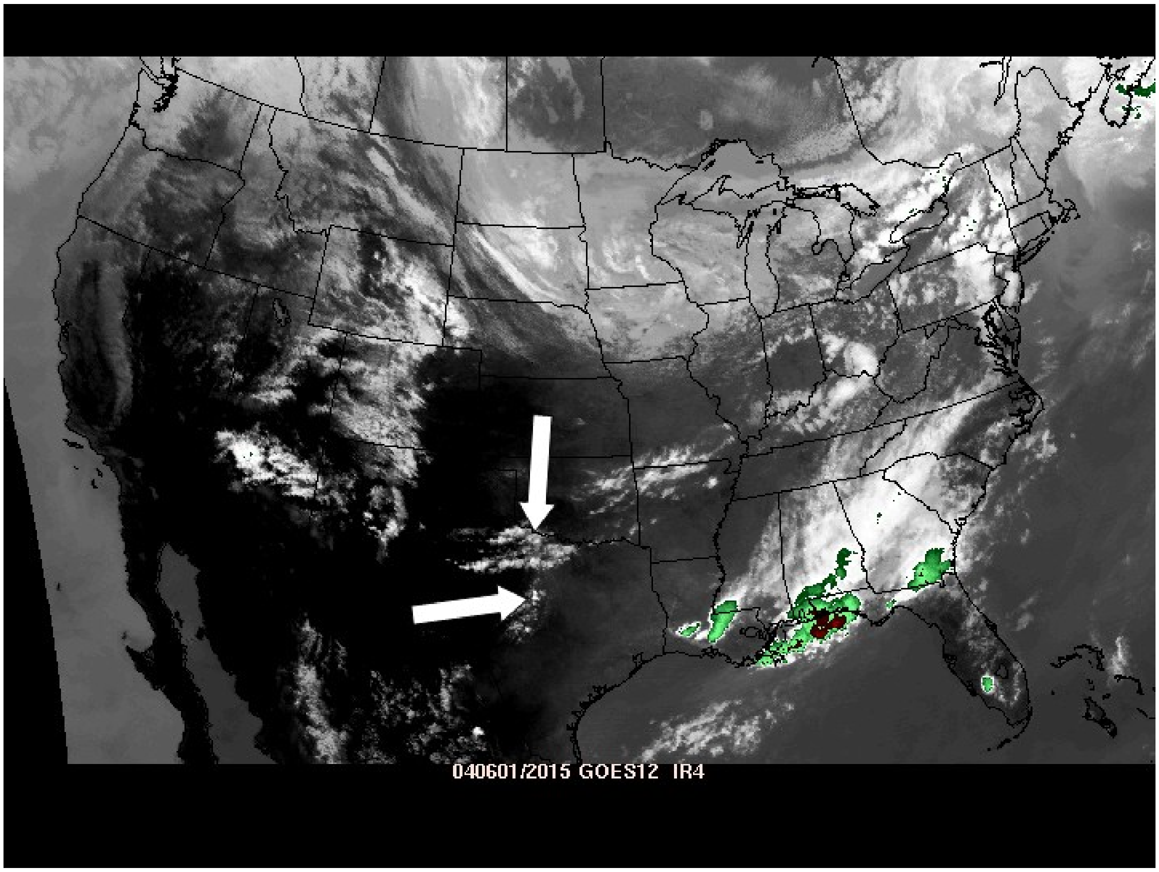

Fig. 6 GOES IR satellite image at 2015 UTC 1 June 2004 showing evidence of convective initiation along the dryline in central Texas and near the front- dryline intersection farther north. A larger area of clouds associated with the shortwave feature is seen between the arrows. (Courtesy of NOAA/NWS/Storm Prediction Center).

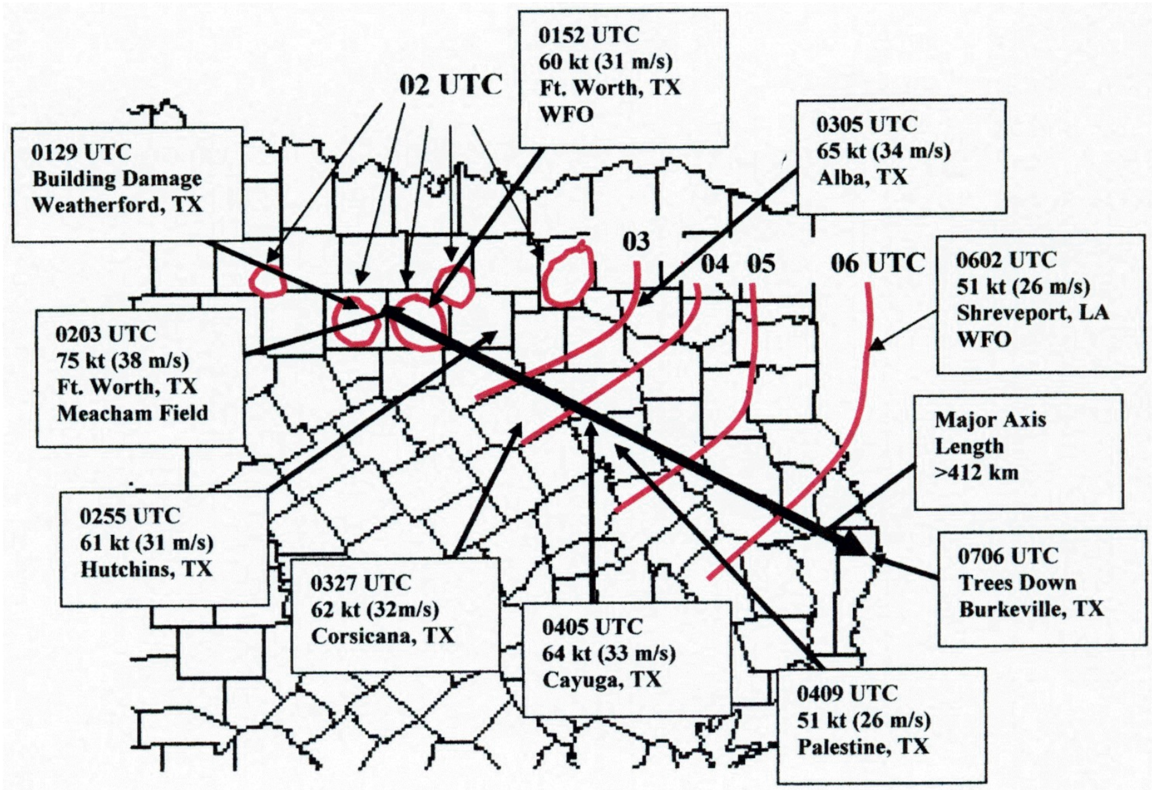

Fig. 7 Diagram showing the major wind reports and positions of the MCS across north Texas 1-2 June, 2004. The positions of major storm cells and the leading convective line are shown in red. The thick black arrow represents the major axis of the event which is more than 400 km.

Source	Number of Reports	% of Total
Emergency Management	34	43.0%
Ham Radio/Spotters	27	34.2%
Co-op and Off-Duty NWS Employees	9	11.4%
Public	5	6.3%
Official Observation Sites	4	5.1%
Total	79	100%

Table 2 Table showing the sources and number of ground truth reports in the National Weather Service – Ft. Worth Severe Weather Log between 2300 and 0500 UTC 1-2 June 2004. These reports represent hail, wind speed, and wind damage for the Ft. Worth County Warning Area (CWA).

Fig. 8 Photo showing one example of tree and power line damage caused by the derecho. This type of damage was widespread and left many without electricity, some for days. (Courtesy of TXU Electric Delivery).

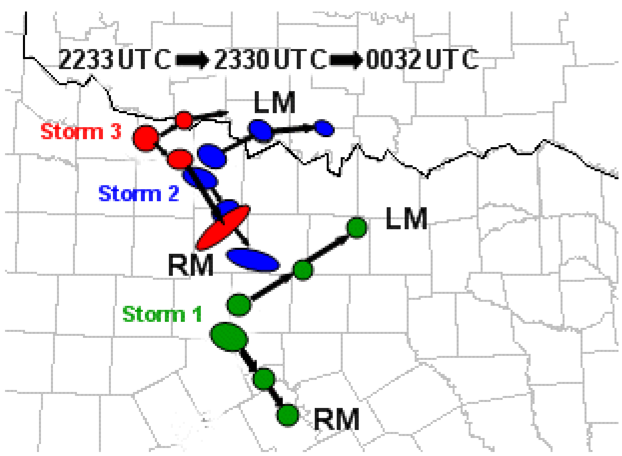

Fig. 9 Schematic diagram of storm motion during the supercell (early) stage of the event. Shown are the three storms that affected north Texas with their right and left-moving members. Storms are numbered and color coded to track their movement over a two hour period. Storm positions at 2233, 2330, and 0032 UTC 1 June 2004 are represented.

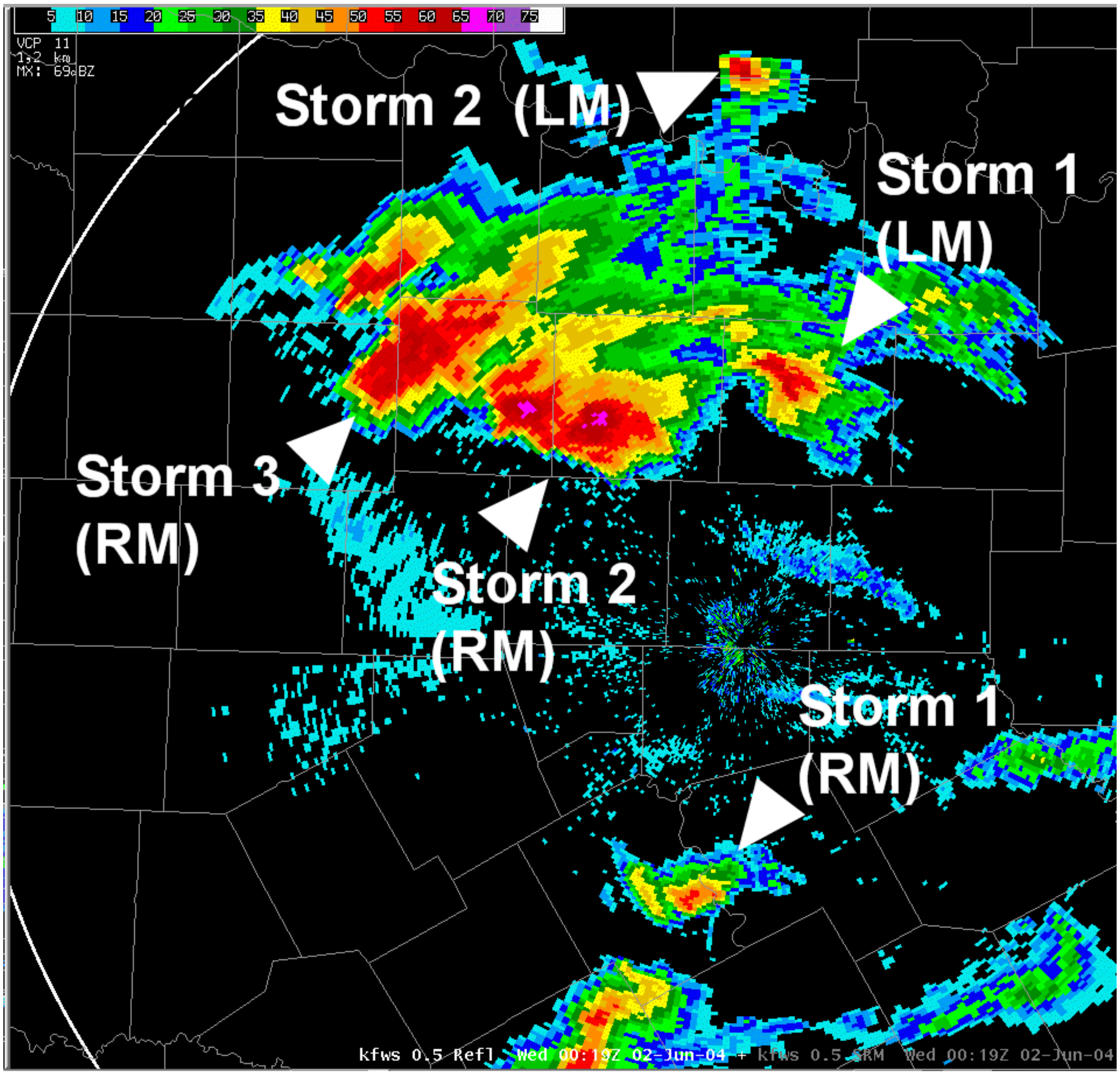

Fig. 10 KFWS 0.5° base reflectivity image at 0019 UTC 2 June 2004 showing individual storms. Storm 2 shows two high reflectivity precipitation cores. Right and left-moving supercells are indicated by RM and LM, respectively.

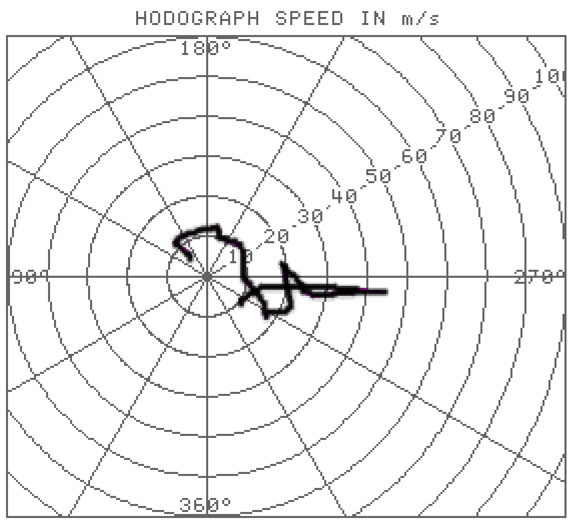

Fig. 11 Hodograph for KFWD 0000 UTC 2 June 2004 sounding. Note the strong veering in the lowest 2.5 km.

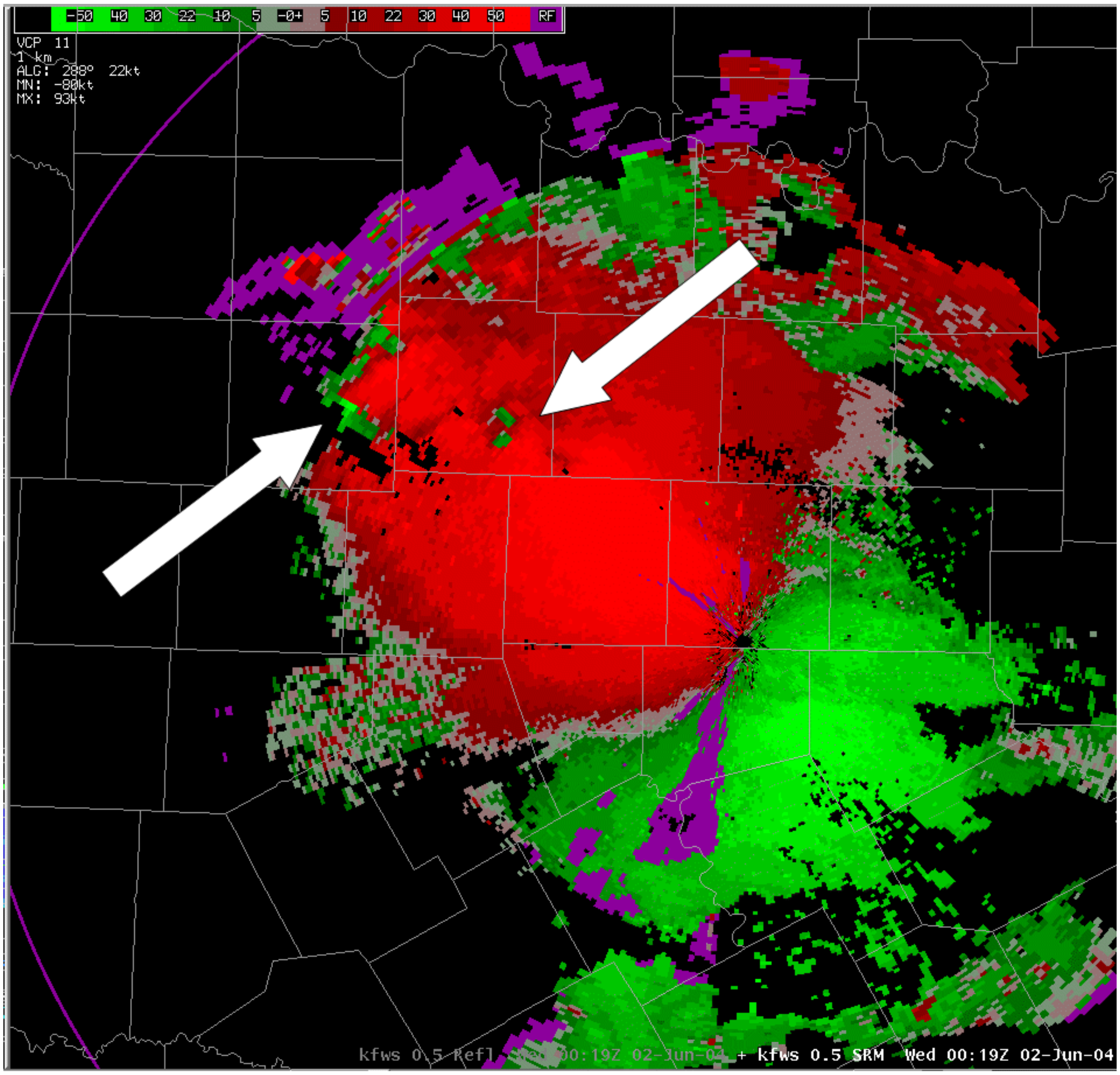

Fig. 12 Storm relative velocity 0.5° tilt from KFWS radar at 0019 UTC 2 June 2004 showing the mesocyclone velocity couplets for Storms 2 and 3.

Fig. 13 Photo showing the base of Storm 2. The striations and flared base were good visual indicators of supercell storm structure. (Courtesy of Jimmy Deguara).

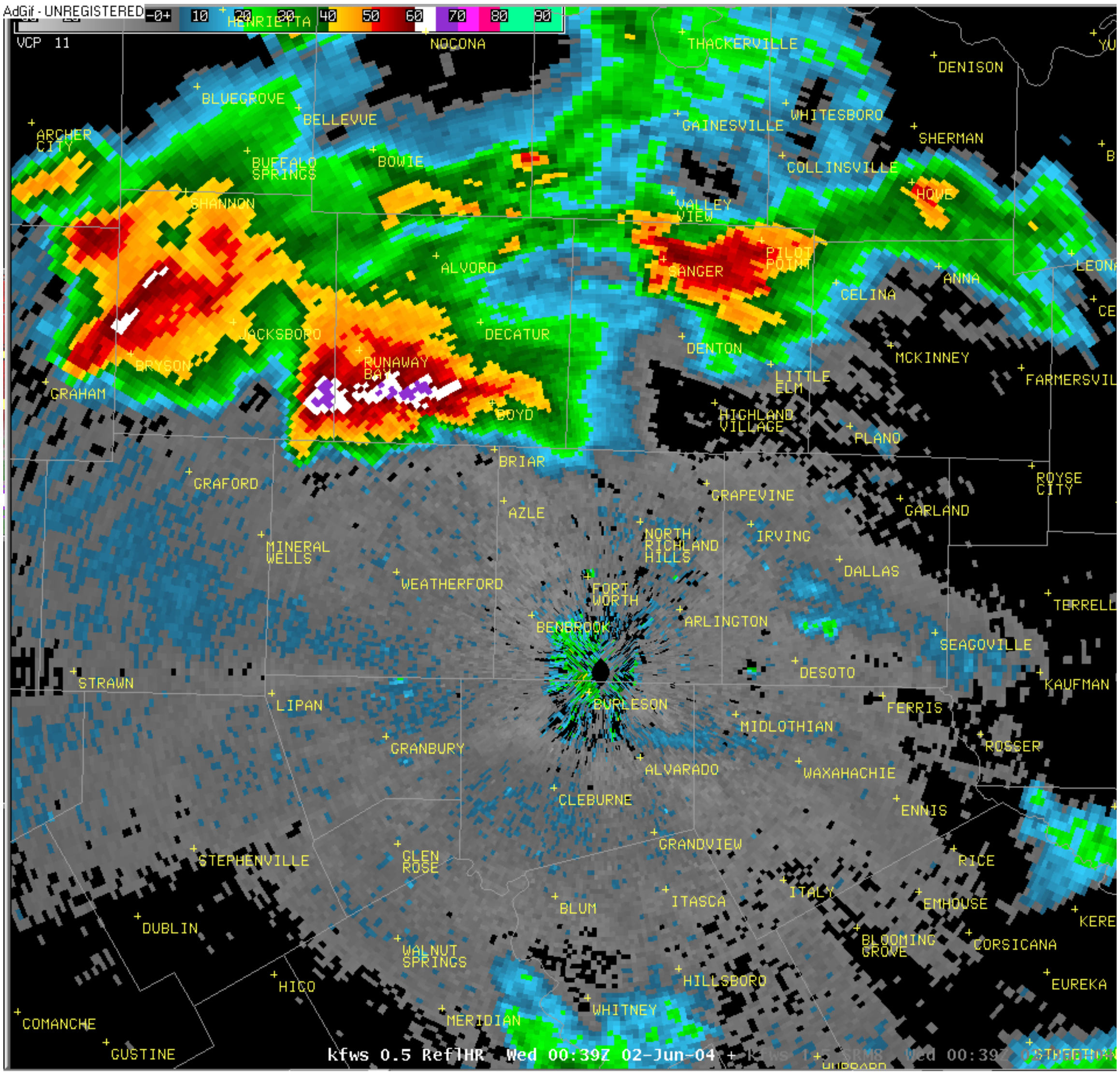

Fig. 14 KFWS base reflectivity loop 0.5° tilt showing the motion and development of Storms 2 and 3 between 0049 and 0314 UTC 2 June 2004.

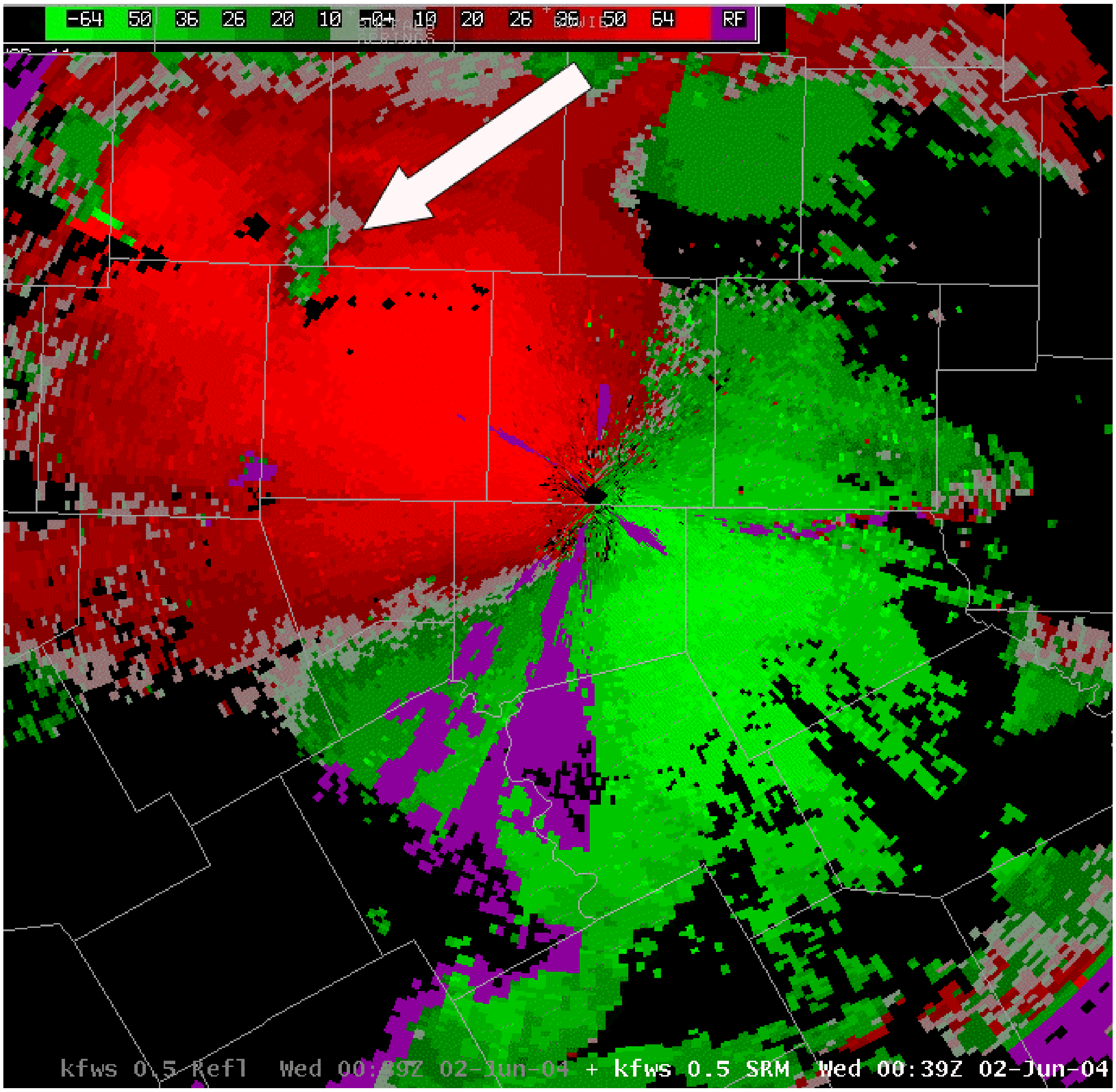

Fig. 15 Storm relative velocity 0.5° tilt from KFWS radar at 0039 UTC 2 June 2004. The arrow indicates an area of broadening inbound velocity in the mid levels of Storm 2.

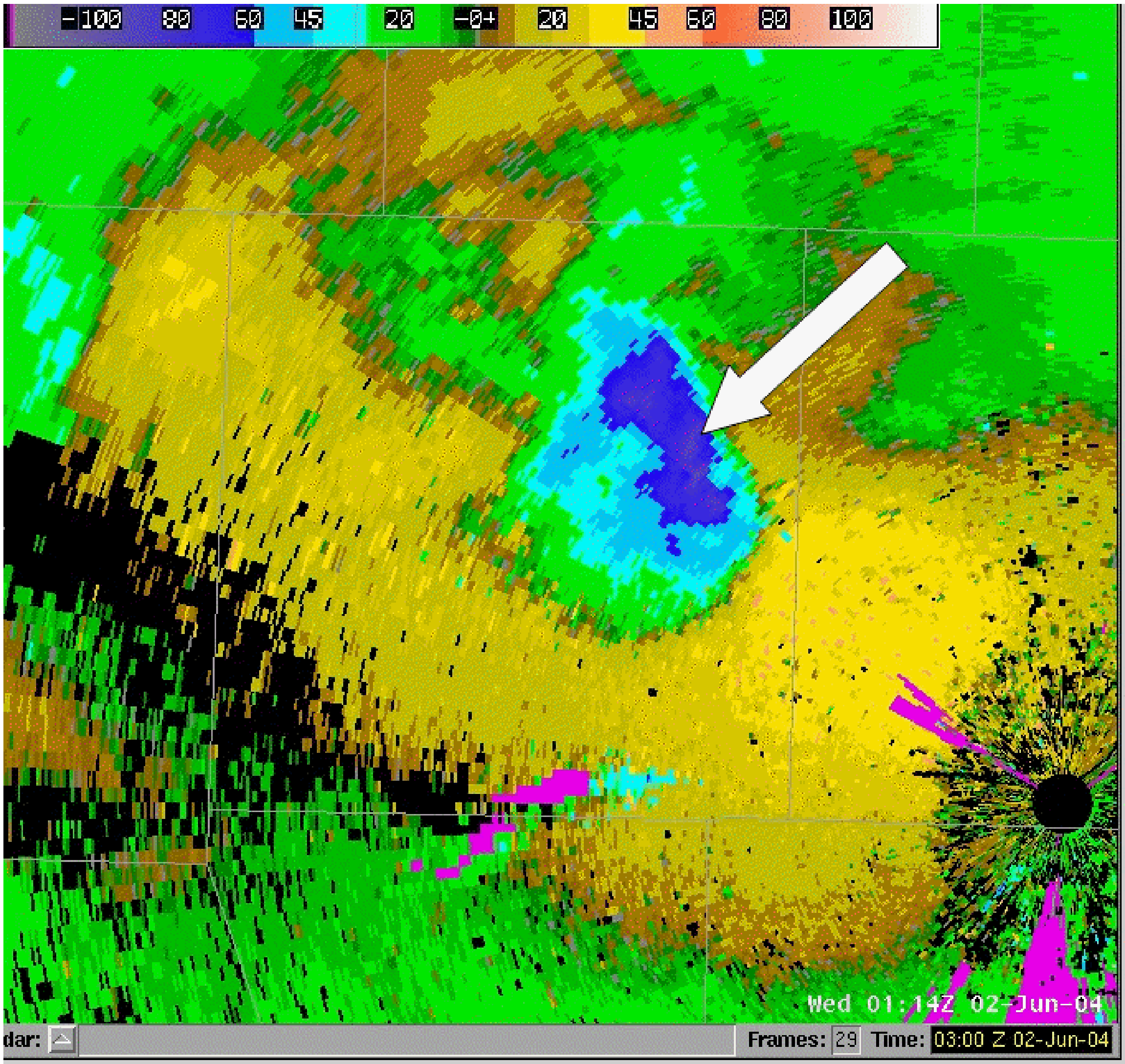

Fig. 16 KFWS 0.5° tilt radial velocity image showing core of intense winds at 0114 UTC 2 June 2004 as Storm 2 passes through eastern Parker County. The winds in this scan reached 93 knots at 1200 ft. AGL (indicated by arrow.)

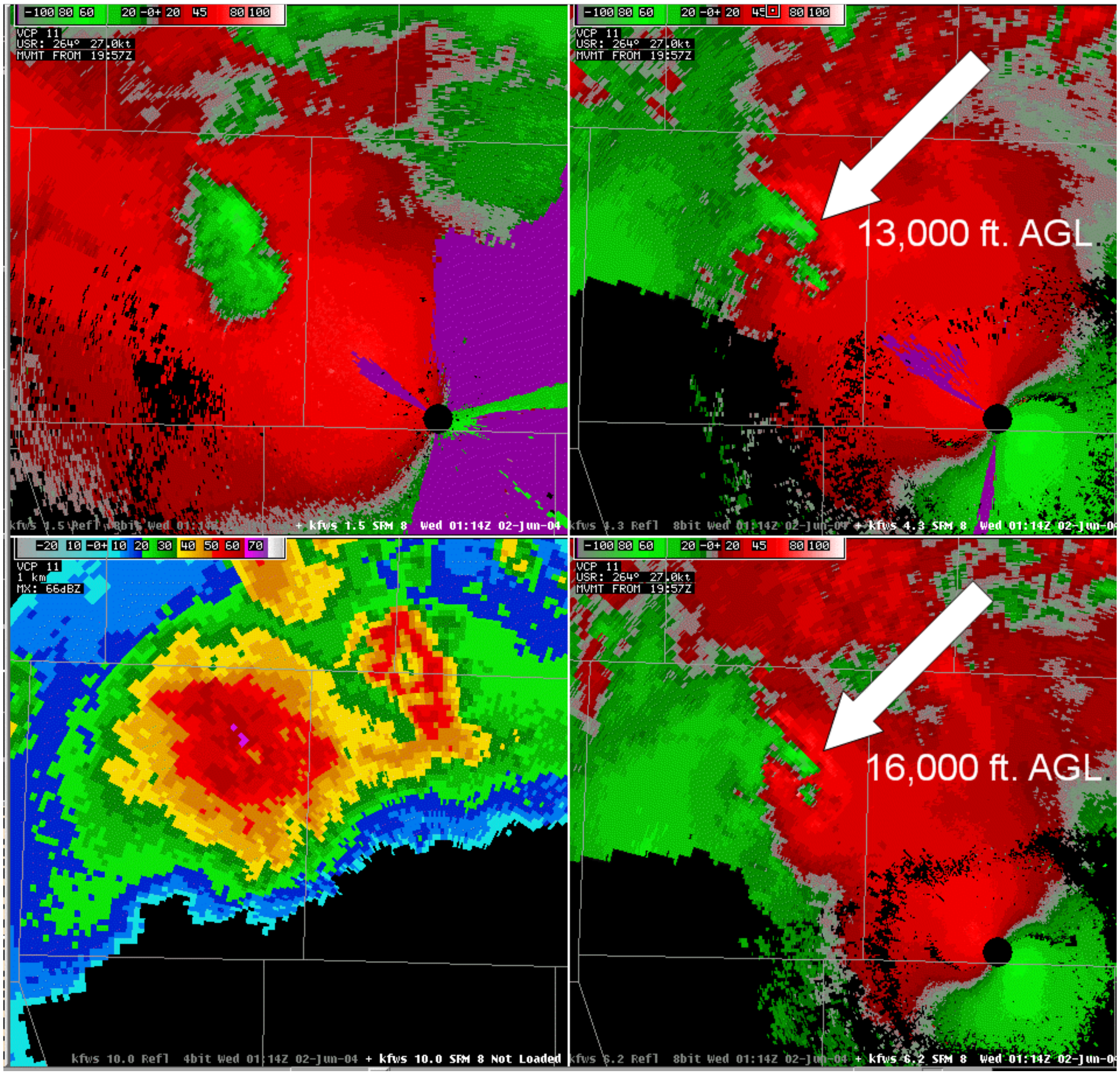

Fig. 17 Four tilt angles: 1.5°, 4.3°, 6.2°, and 10.0° (clockwise), from KFWS radar at 0114 UTC 2 June 2004 showing storm relative velocity in the mid-levels of Storm 2. The arrows indicate a channel of strong rear inflow. Strong outflow winds were occurring in the lower levels of the storm.

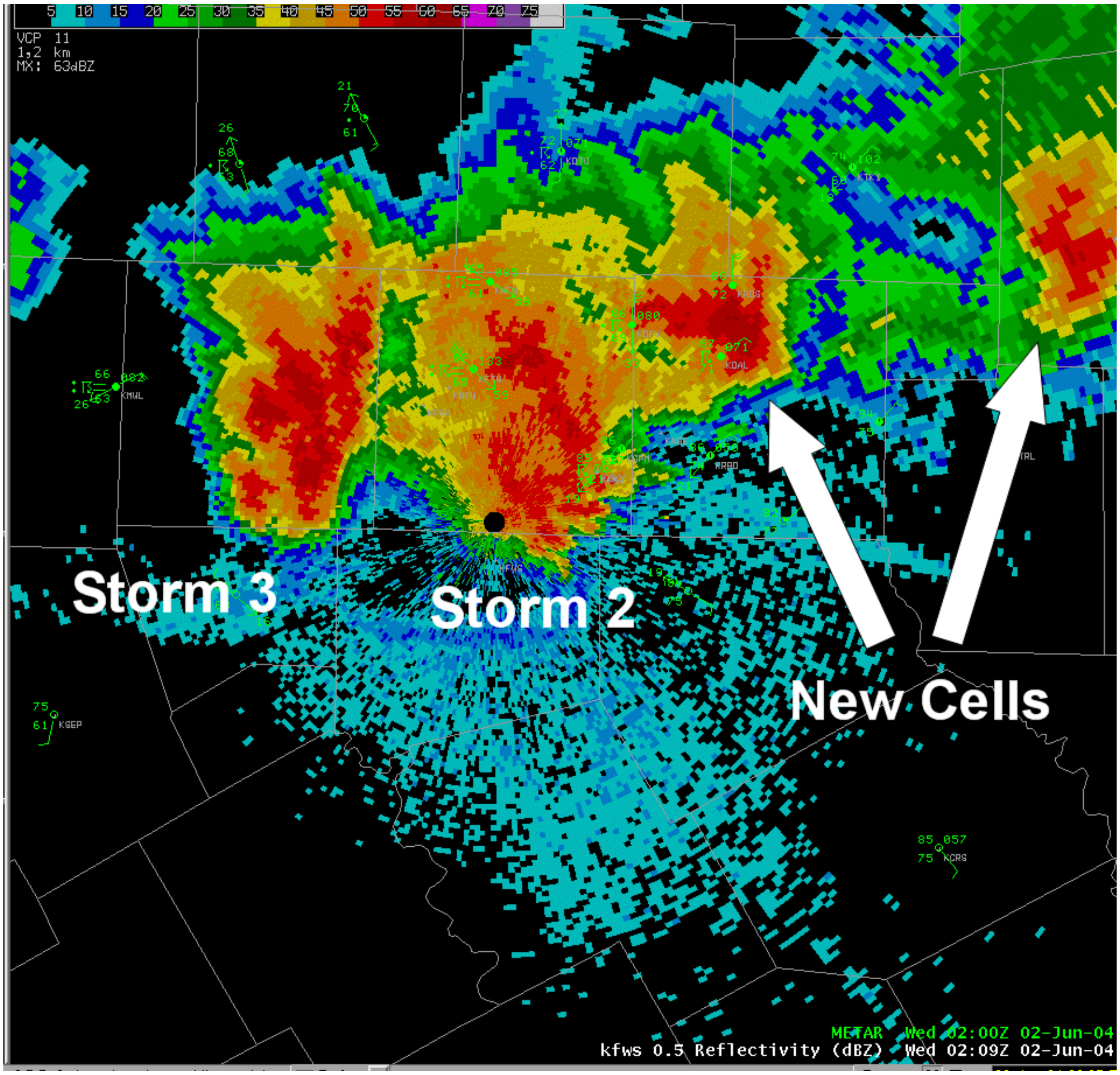

Fig. 18 KFWS 0.5° tilt base reflectivity image at 0209 UTC 2 June 2004 showing storms 2 and 3 with new cells to the east (indicated by arrows.) The two new cells represented the beginning of expansion from discrete cells into a linear MCS.

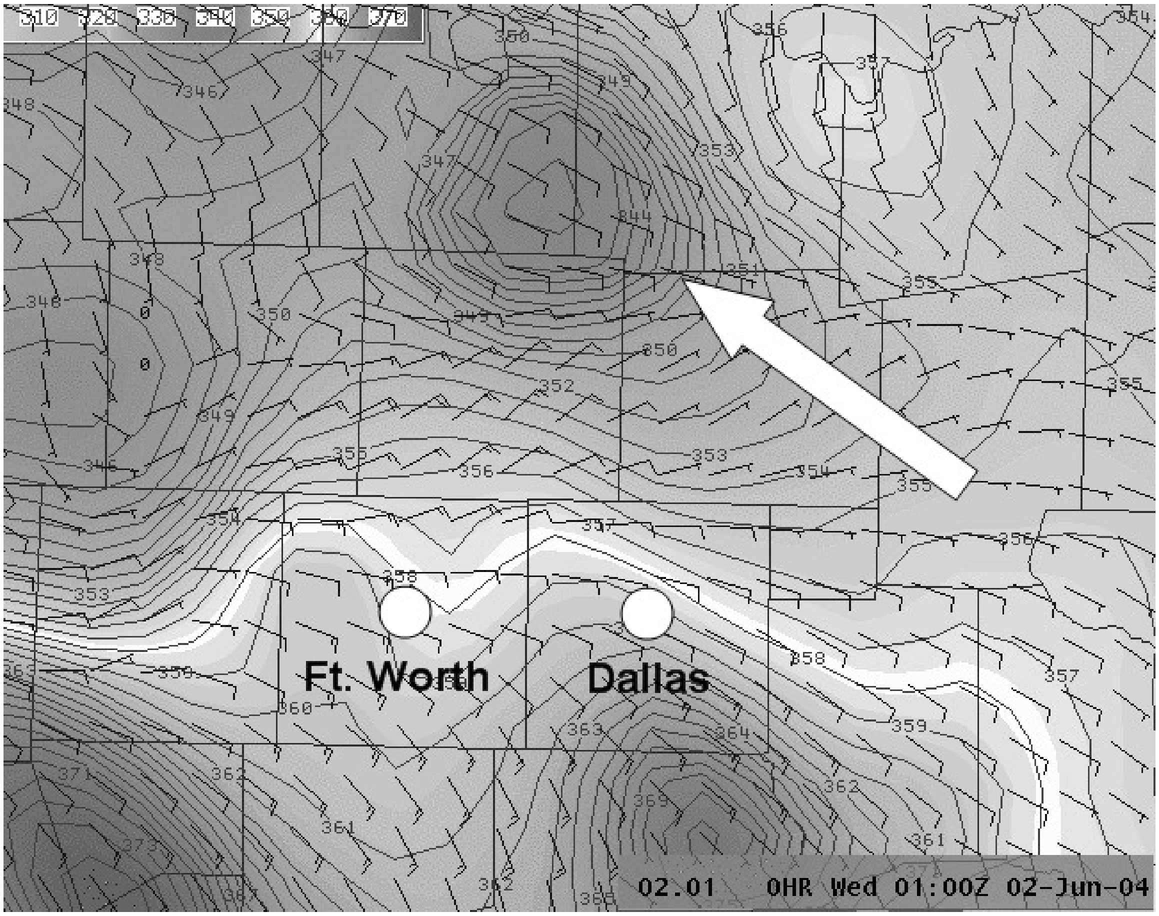

Fig. 19 Surface theta- e analysis for 0100 UTC 2 June 2004. The arrow indicates an area of low theta- e values.

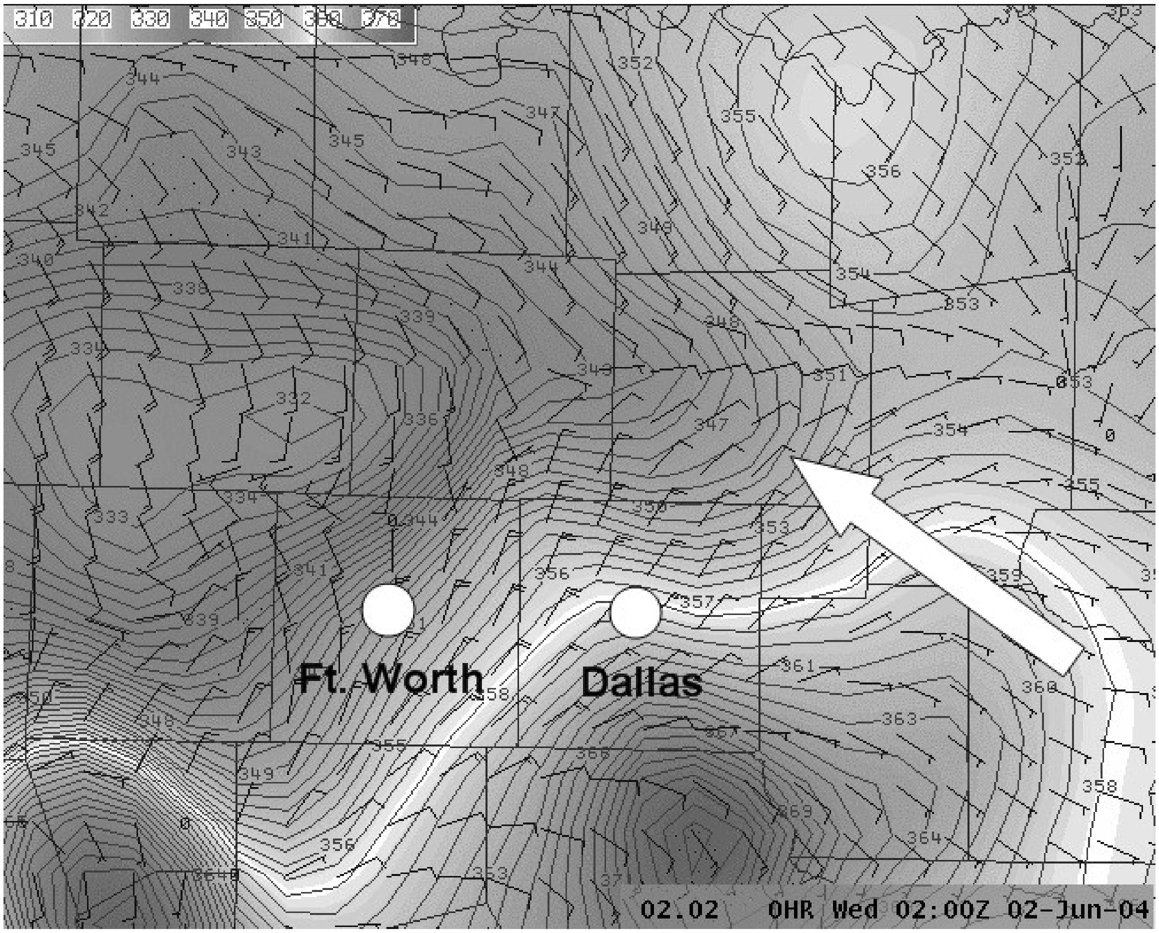

Fig. 20 Surface theta- e analysis for 0200 UTC 2 June 2004. The arrow indicates an area where the low theta- e values and surface cold pool appear to expand southeastward.

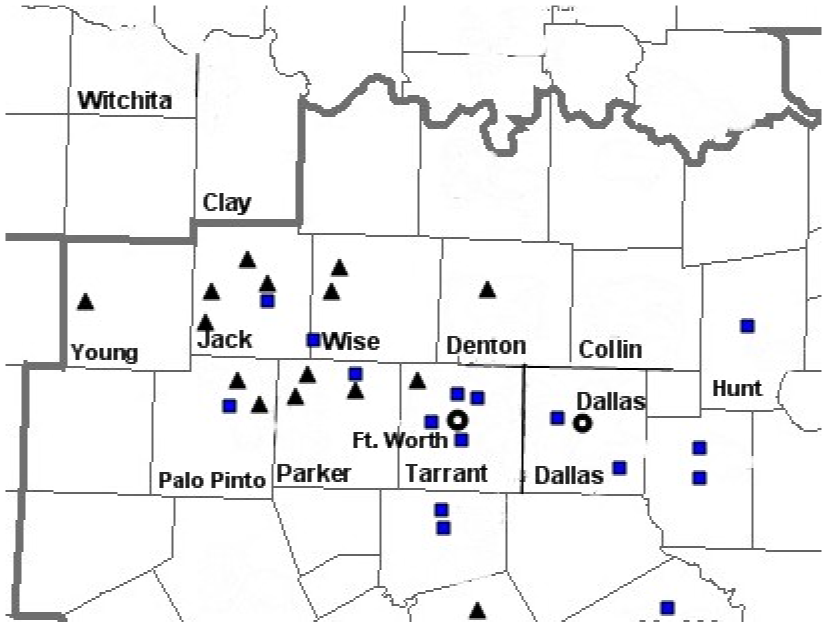

Fig. 21 Diagram showing storm reports in the Dallas-Ft. Worth area as the event transitioned from a hail-producing supercell event to a linear MCS with damaging winds. Triangles represent hail reports over 1.5 inches (3.8 cm) in diameter. Blue squares represent wind reports greater than 50 knots (26 ms^{-1}.)

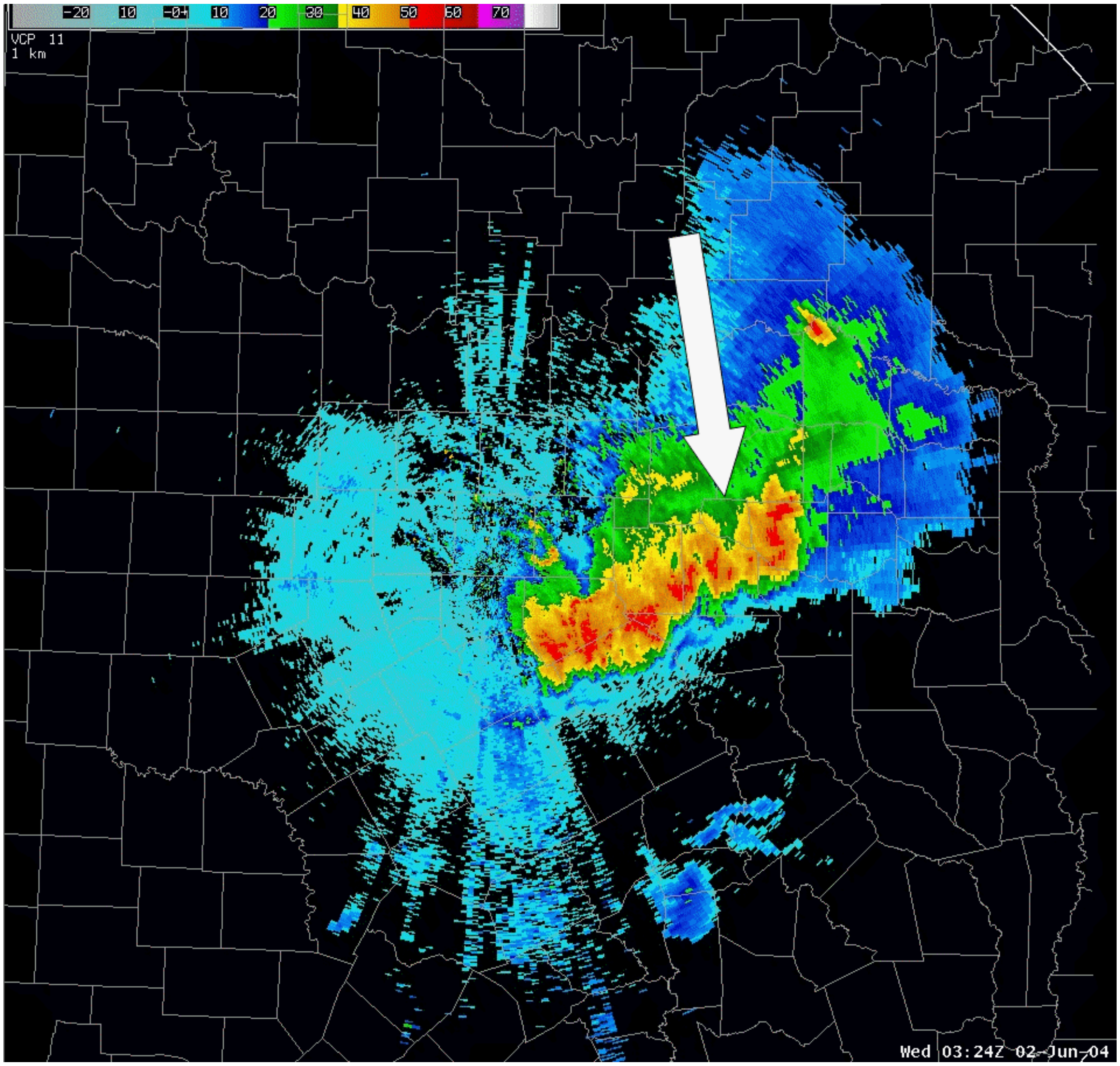

Fig. 22 KFWS 0.5° tilt radar base reflectivity at 0324 UTC 2 June 2004 showing forward- propagating MCS. A rear inflow jet is indicated by the arrow.

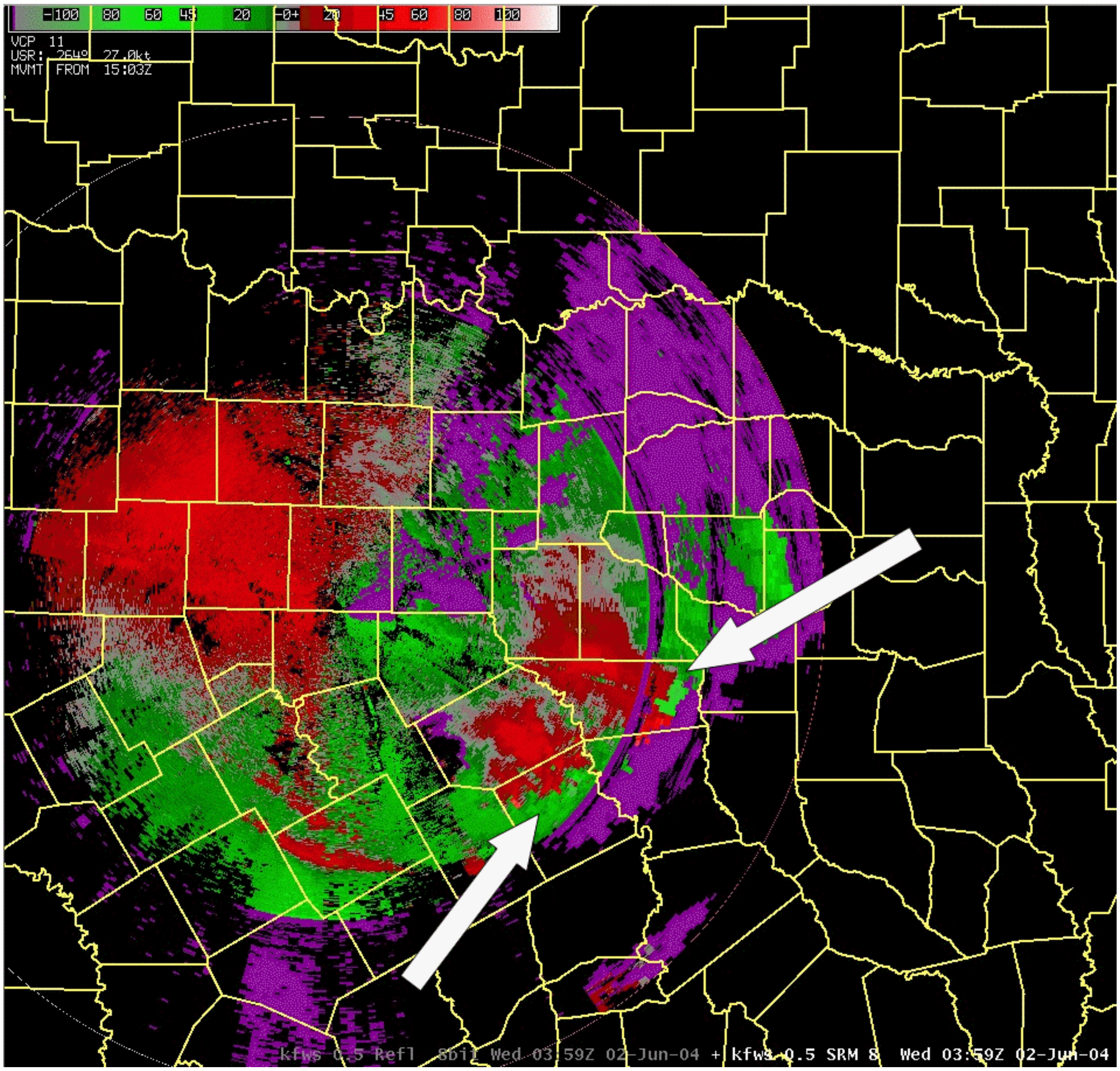

Fig. 23 Strong convergence in discrete zones along the MCS as shown on the KFWS 0.5° tilt storm relative velocity image at 0359 UTC 2 June 2004. The convergence zone on the northeast side corresponds well with the rear inflow jet in **Fig. 21**.