

P12.3 AN ANALYSIS OF THE 22 MAY 2004 FURNAS COUNTY, NEBRASKA TORNADIC SUPERCELL

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1. INTRODUCTION

On 22 May 2004, a supercell thunderstorm (hereafter referred to as the “Furnas County storm”) developed in extreme northwest KS (southwest of McCook, Nebraska) and moved through Furnas and Harlan Counties, Nebraska, spawning 3 tornadoes during its life cycle (Fig. 1). Tornado T1 was the largest (Fig. 2) but because it was in open country and did no significant damage (light damage to a farm and several trees debarked) was given a rating of F1.



Figure 1 – Locations of two tornadoes (T1 and T2) reported to SPC and third tornado witnessed by lead author (T3) associated with Furnas County storm .



Figure 2 – Tornado T1 (as explained in the text) as viewed from near Oxford, Nebraska. View towards the southwest. (Photo by John Monteverdi).

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Post analysis of the radar data shows that the Furnas County was a cyclic classic supercell. Its long life cycle and repetitive tornado production was not related to interaction with subsynoptic scale boundaries (as is often documented in the literature), but to the favorable synoptic scale shear and buoyancy environment into which the storm moved.

The purpose of this paper is to present a brief examination of the synoptic and thermodynamic controls of this event. We also will show how the cyclic nature of the Furnas County storm’s tornado production was consistent with the high values of low level shear found in the storm environment.

2. STORM EVOLUTION AND HISTORY

The Furnas County storm initiated in extreme northwestern KS at around 2000 UTC. The storm quickly became severe and was responsible for many severe hail and wind reports in Cheyenne and Rawlins Counties, Kansas.

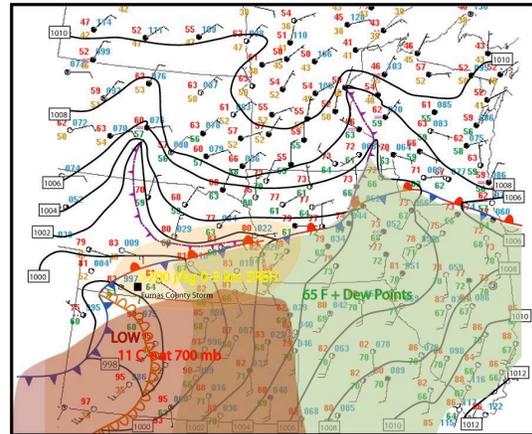


Figure 3 – Subjective analysis of 2200 UTC 22 May 2004 surface data. 0-3 km SREH, surface moisture (dew point) tongue and area of 11°C+ temperatures at 700 mb also shown, as explained in the text in Sections 2 and 3.

At the time of convective initiation, the area of extreme northwest Kansas and extreme southwest Nebraska lay in the northeast portions of a developing wave cyclone, centered in northwest Kansas (Fig 3). Backed surface flow (relative to winds in the mid-troposphere) ahead of a rapidly developing dry line bulge occurred northeast of this center. Storm initiation appeared to take place near the triple point intersection

of cold front, quasi-stationary front and the dry line in the upslope flow of air with high dew points into the western high plains of Kansas and Nebraska.

Analyses of the radar information show that initially the storm moved northeastward with the mid-tropospheric flow (motion vector of $\sim 220^\circ$, 10 m s^{-1}). Southwest of McCook, Nebraska, the storm became a supercell, and it became a deviate mover (motion vector of $\sim 260^\circ$, 12 m s^{-1}).

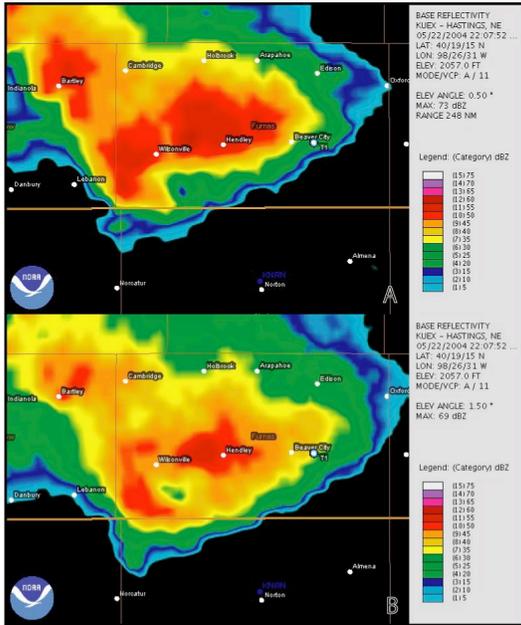


Figure 4 – Base reflectivity (2207 UTC) from KUEX at 0.5° and 1.5° degree tilts, illustrating BWER, as explained in text. T1 shows the eventual position of the first tornado near Beaver City, seen in Fig. 2. The KUEX radar was intersecting the storm at a range of 146 km and at heights of 2500 m (0.5° tilt) and 5020 m (1.5° degree tilt).

A bounded weak echo region (BWER) developed as the storm entered southwest Furnas County. At 2207 UTC, the 0.5° base reflectivity from the Weather Surveillance Radar 88 Doppler (WSR-88D) at Hastings, Nebraska (KUEX) showed a well-developed hook echo (Fig. 4a) while the 1.5° base reflectivity (Fig 4b) depicted a circular echo free region over the inflow notch shown in Fig. 4a.

During the next 2 hours the radar evolution of the storm was complex. Several times the low level hook became disorganized to be replaced by a new mesocyclone-generated hook further south. During the first of these cycles, the first tornado developed near Beaver City. The tornado (Fig. 5) formed on the extreme northeast (forward) portion of the lower level “horseshoe” lowered base, just ahead of the rear flank downdraft (RFD) cut.

The tornado persisted for around 8 minutes until it dwindled through its “rope out” stage. During that life cycle, the lead author was located near Oxford, Nebraska (indicated by A on Fig. 6), approximately 10 km away

from the tornado to the southwest (T1 on Fig. 6). The large horseshoe base, flared ahead of the RFD was very striking (green schematic on Fig. 6).

The radar imagery at the time of the tornado, 2233 UTC, shows the reflectivity at the time of a cycle. The forming new hook (Fig 7a) was just east of Beaver City, while the older hook dissipated to the northwest. The storm relative velocity plot (Fig. 7b) shows a well demarked couplet, with approximately 50 knots of “rotational velocity” across the circulation (classifying this mesocyclone as strong). KUEX was too distant from the storm at this time to detect a Tornado Vortex Signature (TVS) (TVSSs subsequently detected in the next several cycles of the storm).



Figure 5 – The first tornado (T1 on Fig. 1) associated with the Furnas County storm, near Beaver City, view to the southwest (see Fig. 6). (Photograph by John Monteverdi)

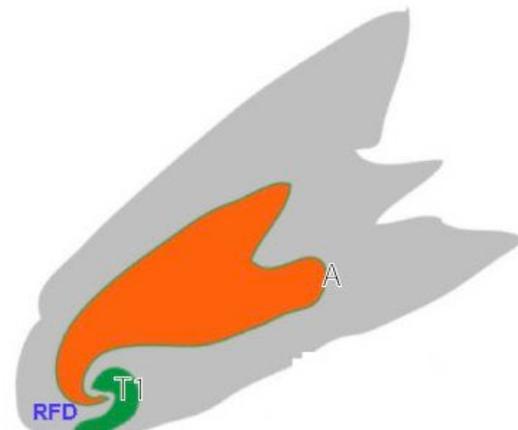


Figure 6 – Schematic diagram showing (cloud and radar features) the location of the photographer near Oxford, Nebraska (A) in relation to the Beaver City tornado (T1).

The Furnas County storm continued to move east-northeastward over the next several hours. As it did so, it underwent at least two more cycles and produced tornadoes T2 and T3 (see Fig. 1). The visible satellite image shows the storm at the time of tornado T1 (Fig. 8). Other storms were developing along the synoptic-scale boundary extending along the Interstate 80 corridor north of the boundary into north-central Nebraska (Fig. 3).

At the time of Fig. 8, the Furnas County storm appears to be the only storm rooted in the rich surface moisture. However, this would soon not be the case, as a new storm developed on the outflow boundary east of the Furnas County storm. This new storm would become the Lancaster County storm that devastated Hallam, Nebraska.

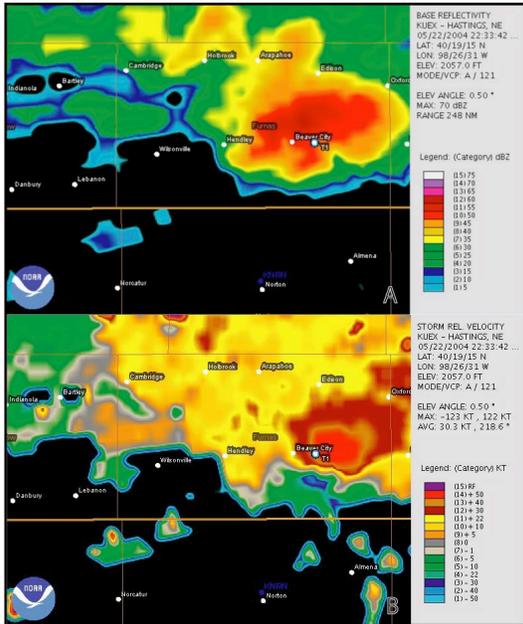


Figure 7 – (a) Base reflectivity and (b) storm relative velocity plots (2233 UTC) from KUEX at 0.5° tilt, at exact time of Beaver City tornado report (T1). The KUEX radar was intersecting the storm at a range of 115 km and at heights of 1800 m (0.5° tilt) and 3800 m (1.5° degree tilt).

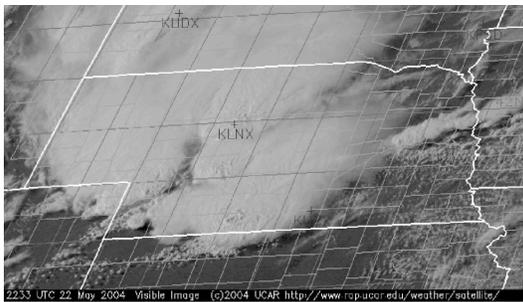


Figure 8 – Visible Satellite image at 2233 UTC, the exact time of the F1 Beaver City, Nebraska tornado. The Furnas County storm is southern most storm, just north of Kansas border. (Image courtesy Greg Thompson, UCAR)

3. SYNOPTIC AND THERMODYNAMIC CONTROLS ON FURNAS COUNTY STORM

3.1 Synoptic Scale Environment

Several key features in the synoptic-scale environment (in addition to those mentioned in Section 2

above) contributed both to the initiation of the Furnas County storm and to its evolution into a cyclic supercell. The synoptic-scale environment also created a low level shear environment so favorable for supercell tornadogenesis that the absence of boundaries in the near-storm environment did not deter the formation of tornadoes. Such boundaries have been identified as key players in many significant supercell tornado outbreaks (see, e.g., Markowski et al. 1998 and Rasmussen et al. 2000).

During the afternoon hours of 22 May 2004, a strong shortwave trough (seen in the height fields in Figs. 9a and 9b) in the middle and upper troposphere dominated the region. This trough was associated with substantial upward motion in the middle troposphere over the southern and central Nebraska.

Pressure falls ahead of the trough (not shown) were associated with the development of a complex surface low pressure system (Fig 3). The circulation around this center caused the development of a wave along the front and encouraged the progression of a dry line bulge into northwest Kansas and southwestern Nebraska.

A number of factors focused synoptic and sub-synoptic scale lift in the lower mid troposphere over southern Nebraska on March 22. First, differential cyclonic vorticity advection and warm advection were associated with quasigeostrophic forcing for mid-tropospheric layer lifting over the area. The quasigeostrophic effects can be diagnosed by the area of 700 mb cyclonic vorticity advection by the thermal wind inferred from Fig. 9c.

Second, solenoidal lifting along and just south of the synoptic-scale boundary (Fig. 3), and roughly coincident with the greatest temperature gradient at 700 mb (Fig. 9c), probably was an additional source of lift. Finally some weak mid-tropospheric upward vertical velocity, associated with convergence extending south into Kansas along the dry line bulge (Fig. 3), is also evident in Fig. 9b.

Above 850mb, west-southwest winds had brought a warm, dry layer over the underlying very moist air mass at the surface. The resulting cap was very strong south of the Kansas border, and was roughly demarked by the 11°C 700 mb isotherm (Figs. 3 and 9a).

The presence of strong winds in the mid and upper troposphere (not shown) also helped create a favorable deep layer (i.e., 0-6 km) shear environment for supercells over Nebraska. But, of special note, is the area of markedly backed strong southeasterly flow that extended from extreme southwest Nebraska eastward just north of the Kansas border (Fig. 3). This flow environment created low level shear values (e.g., 0-1 km) of high magnitudes, consistent with those experienced across outflow boundaries.

3.2 Thermodynamic and Shear Environment

The thermodynamic environment featured moderate to strong instability over central and southern Nebraska with surface based Convective Available Potential Energy (sbCAPE) of between 2000 and 3000 J/kg at 0000 UTC (Fig. 10). The greatest values were

associated with the tongue of high dew points that had curled around the dry line bulge discussed above (Fig. 3). It is interesting to note that region experiencing values of Convective Inhibition Energy (CINH) suggestive of a strong capping inversion or lid (values of < -50 J/kg) were coincident with the area experiencing 700 mb temperatures of roughly 11°C or greater (see Fig. 3). Thus, the values shown in Fig. 10 suggest that little or no inhibition existed for surface based convection in the area of high sbCAPE values in southern Nebraska in the afternoon hours of 22 May.

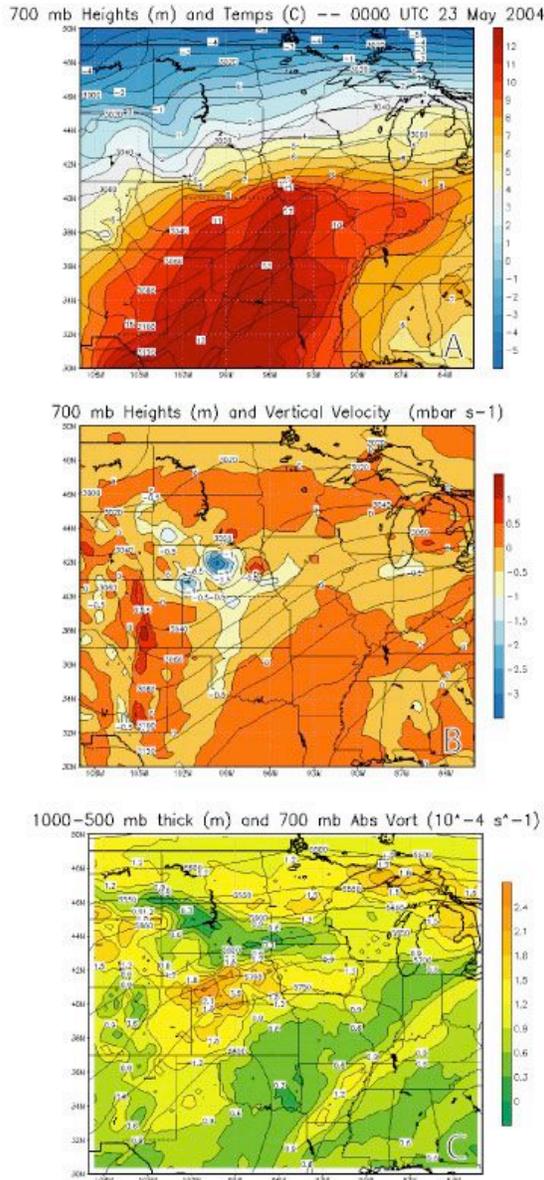


Figure 9 – NCEP Reanalyses of key 700 mb features 0000 UTC, 23 May 2004. (a) 700 mb heights (m) and temperatures (C); (b) 700 mb heights (m) and vertical velocity ($\mu\text{bar s}^{-1}$); (c) 1000-500 mb thickness (m) and 700 mb absolute vorticity (s^{-1}).

The KTOP (Topeka, KS) rawinsonde ascent was closest to the Furnas County storm at 0000 UTC on 23 May (Fig. 11a). This ascent was deep in the warm air south of the boundary, and showed the lid clearly (Fig. 3), while the KOAX (Omaha, NE - Fig. 11b) sounding was just north of the synoptic scale boundary and away from the lid edge.

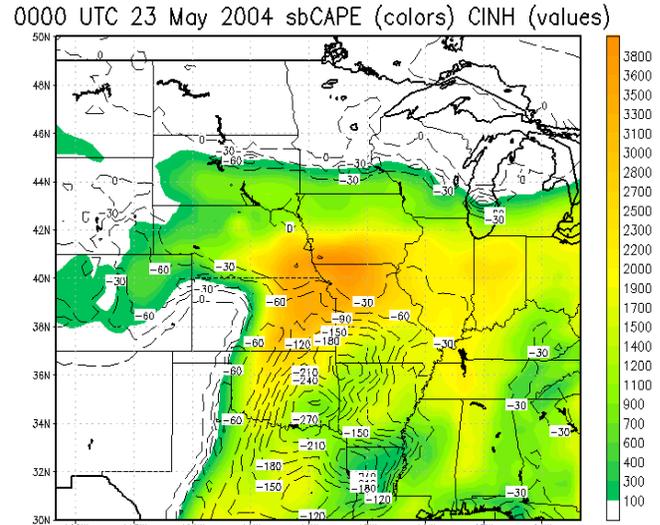


Figure 10 – NCEP reanalysis of surface based CAPE (colors) and CINH (dashed) in J/kg at 0000 UTC 23 May 2004.

The greatest difference between the two soundings is the warmer temperatures in the 850-700 mb layer at KTOP. These were associated with the surge of the elevated mixed layer (EML) northeastward over Kansas during the day. The thermodynamic profile in the vicinity of the Furnas County storm would have been a merge of the two soundings, and without the lid.

Another important point that should be made is that only in the region between the synoptic scale boundary (evident on Fig. 3) and the Kansas border was the dew point depression small enough to yield Lifting Condensation Levels (LCL) very close to the ground (< 4000 feet) and also very close to the parcel's Level of Free Convection (LFC). Recent studies have shown that tornadogenesis is favored in areas with small temperature and dew point spreads (Davies 2004).

The wind information plotted on Fig. 11 is consistent with the locations of KTOP and KOAX relative to the synoptic-scale boundary. KOAX reported northeast winds in the convective boundary layer, since that location was north of the synoptic-scale boundary. KTOP had south southeasterly winds in the same layer.

To construct a proximity hodograph for the Furnas County storm, the authors used the Vertical Azimuth Display (VAD) wind profile for KUEX at 2330 UTC. Unfortunately, there were many missing levels for earlier times, including the time of tornado T1. However, the hodograph would have captured the shear characteristics both of the environment at the time of tornadoes T2 and T3, and of the environment into which the Furnas County storm was moving as it became cyclic.

The hodograph (Fig. 12) is striking. It contains a large anticyclonic loop from 0-3 km. Such a large loop is associated with dynamic pressure forces creating strongly deviant right moving supercells, often associated with mesocyclone tornadoes (Rotunno and Kemp 1985).

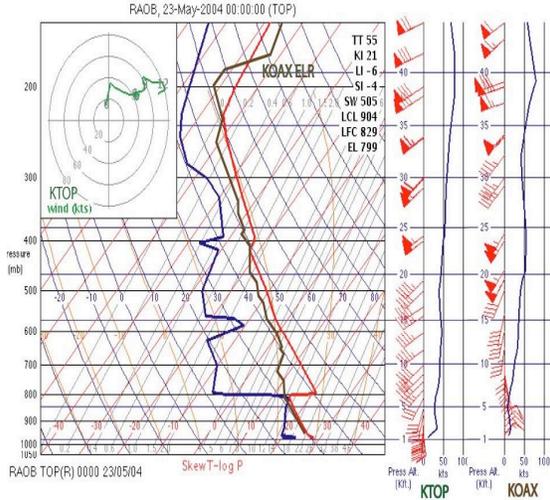


Figure 11 - 0000 UTC 23 May 2004 (a) KTOP environmental (red) and dew point (blue) lapse rates and (b) KOAX environmental lapse rate (ELR) (brown). Inset is 0000 UTC KTOP hodograph. Mandatory and significant level wind information for KTOP and KOAX plotted at right.

The motion of hypothetical splitting storms (given the wind profile shown in the hodograph) is also plotted on Fig. 12. According to the algorithm used to estimate the predicted storm motion (Bunkers et al. 2000), the left moving storm's motion vector should have been on the hodograph; the left movers would not be supercells and would be suppressed. These characteristics were verified by the radar animations examined by the authors (not shown) that showed that the left moving storms in southern Nebraska had brief life cycles and tended to be weak.

A remarkable feature of the hodograph is the intense low level shear suggested by the anticyclonic loop, with a strong kink between 1 and 2 km. Such a kink was observed in the VAD-derived hodographs in Oklahoma on the day of the May 3, 1999 tornadic supercell outbreak (Thompson and Edwards 2000).

The calculated 0-1 km shear from Fig. 12 is $8.0 \times 10^{-2} \text{ s}^{-1}$. Such shear, if tilted into the vertical and stretched, would be converted into vertical vorticity with a magnitude comparable to that found with weak and moderate tornadoes (Rasmussen et al. 2000). Rasmussen et al. (2000) found such values along boundaries, and presented a case study example of a non-tornadic supercell becoming tornadic when it intercepted and "ingested" such boundaries.

In the present case, the low level shear values were so great that any supercell that formed in such an environment would rapidly process through the so-called supercell cascade to tomadogenesis. In addition, as long

as such a storm continued to move through such a favorable buoyancy and shear environment it would continue to produce tornadoes cyclically.

The low level shear favorable for formation of mesocyclones and tomadogenesis is also dramatized by the 0-3 km Storm Relative Helicity (SREH) of $516 \text{ m}^2 \text{ s}^{-2}$. This value exceeds the values nominally considered favorable for the development of strong mesocyclones (Davies-Jones et al. 1990) and is obviously consistent with what was observed in the radar evolution of the storm. The area in Nebraska that had values of 0-3 km SREH $> 200 \text{ m}^2 \text{ s}^{-2}$ at 0000 UTC 23 May 2004 is highlighted on Fig. 3.

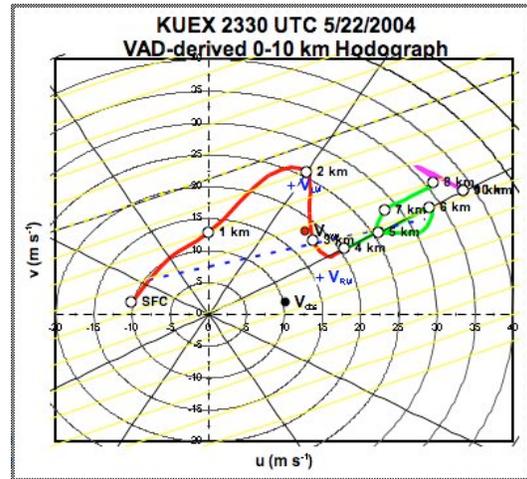


Figure 12 – Proximity Hodograph for the Furnas County storm obtained from the KUEX VAD wind profile at 2330 UTC, as explained in the text.

Finally, the deep layer shear (0-6 km), calculated from the hodograph shown in Fig. 11, was favorable for supercells (Weisman and Klemp 1986). The deep layer shear is a simultaneous control on both (a) the storm ventilation, ensuring that the precipitation core does not interfere with the updraft; and (b) the development of mid-level updraft rotation by providing adequate environmental deep layer shear which, when tilted into the vertical by the updraft, is favorable for the formation of mid-level mesocyclones. In the present case, the value of deep layer shear was $10.5 \times 10^{-3} \text{ s}^{-1}$, a magnitude that Weisman and Klemp (1986) classify as strong.

A summary of the parameters discussed in this section is included in Table 1. The parameters are based upon an evaluation of the KTOP and KOAX soundings (Fig. 11), NCEP reanalysis sbCAPE and CINH (Fig. 10) and the proximity hodograph of KUEX VAD wind profile information (Fig. 12).

4. SUMMARY

There were many unremarkable factors favoring both thunderstorm storm initiation and tornadic supercell mode that coincidentally came into play on May 22, 2004 in south-central Nebraska. These include favorable deep layer shear, adequate to rich low level moisture and

a thermodynamic environment favorable for deep convection. All of these can be considered to be a consequence of the synoptic-scale environment.

sbCAPE	2900 J/kg
0-6 km Shear	$10.5 \times 10^{-3} \text{ s}^{-1}$
0-3 km Storm Relative Helicity	$516 \text{ m}^2 \text{ s}^{-2}$
Actual Storm Motion	260/20 kts
0-1 km Shear	$80.0 \times 10^{-3} \text{ s}^{-1}$

Table 1 : Parameters calculated on the basis of the 2330 UTC KUEX hodograph and KTOP sounding given in Fig. 11.

Nevertheless, we believe that the Furnas County tornadic supercell represents a relatively unusual case. Recent submissions to the refereed literature rightfully focus on the role of storm-boundary interaction in the development of supercell tornadoes. However, this case appears to be an illustration of how a storm developing in a unique low level environment, one in which the “background” low level shear values are already favorable for supercell tornadogenesis, can become a repetitive tornado producer.

In this case, the 0-1 km shear values were of a magnitude usually found across outflow boundaries. In fact, the overall pattern setup on May 22 appears to have many similarities to that documented by Thompson and Edwards (2000) in Oklahoma on 3 May 1999. On that day there were also no obvious outflow or synoptic-scale boundaries (beyond a double dry line) present and it appeared that many storms proceeded to tornadogenesis merely by processing the low level shear already present in the environment.

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6. ACKNOWLEDGEMENTS

The authors gratefully acknowledge Greg Thompson of UCAR' for providing us with an archived version of the visible satellite image. We also thank Chuck Doswell for his critical review of the manuscript. The entire documentation of this event would not have been possible were it not for the steadfast and intelligent company of my fellow storm chasers, Thom Trimble and Chuck and Vickie Doswell.