## 16.5 Significant Tornadoes in Environments with Relatively Weak Shear

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### 1. Introduction

Significant tornadoes that occur in environments of relatively weak detectable low-level and deep-layer shear (e. g., 0-3 km storm-relative helicity less than around 125 $m^2s^{-2}$ and boundary-layer to 6 km shear of only 20-30 kts) continue to be documented. Recent examples of damaging tornadoes in this category are the Jackson, Nebraska tornado on 8/17/01 (rated F2), the Myrtle Beach tornado on 7/6/01 (rated F2), and one of the Lamar, Colorado tornadoes on 5/29/01 (rated F3, see Hodanish and Davies 2002, this volume). Although these tornadoes were associated with storms that at times exhibited supercell characteristics, the shear environments appeared generally weaker than accepted shear guidelines typically associated with supercells and supercell tornadoes (e.g., Davies and Johns 1993, and Rasmussen and Blanchard 1998).

Examination of the sub-synoptic environments for several events of this type reveals some common features. These include a well-defined pre-existing surface wind shift boundary, sizable convective available potential energy (CAPE) *in low-levels* along with small convective inhibition (CIN), and motion that resulted in storms remaining on or near the boundary with deviation considerably to the right of the mean wind. While the mechanisms for tornado development in such cases are unclear, the combination of these factors appears to contribute to a local scenario and environment supportive of tornadoes. Pattern recognition of these features may help with short-term awareness for forecasters.

This paper will briefly examine three cases, followed by a discussion documenting detectable features and their possible relevance to tornadoes.

### 2. Jackson, Nebraska tornado case 8/17/01

This was an event in northwest upper flow, with a southeast-moving upper trough (not shown) helping to generate thunderstorms at late afternoon along a pre-frontal surface wind shift boundary, oriented northeast to southwest (Fig. 1). Although 0-3 km storm-relative helicity (SRH) was somewhat maximized ahead of the boundary (see Eta-derived analysis in Fig. 1), both SRH and boundary-layer (BL) to 6 km shear were generally weak across western Iowa and eastern Nebraska. Figure 1 suggests that SRH was less than 120 $m^2s^{-2}$ across this area, while Eta-derived BL-6 km shear (not shown) was less than 30 kts. Vertical shear was also rather weak on the RUC-2 analysis profile for Sioux City, Iowa (see Fig. 2)

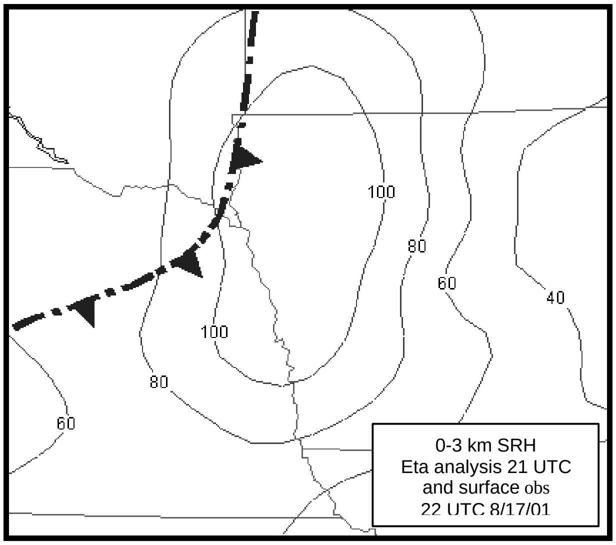

Figure 1. Estimated 0-3 km SRH (20 $m^2s^{-2}$ contours) for 22 UTC 8/17/01 using Eta model analysis at 21 UTC merged with 22 UTC surface observations. Pre-frontal wind shift boundary is heavy dot-dashed line with barbs.

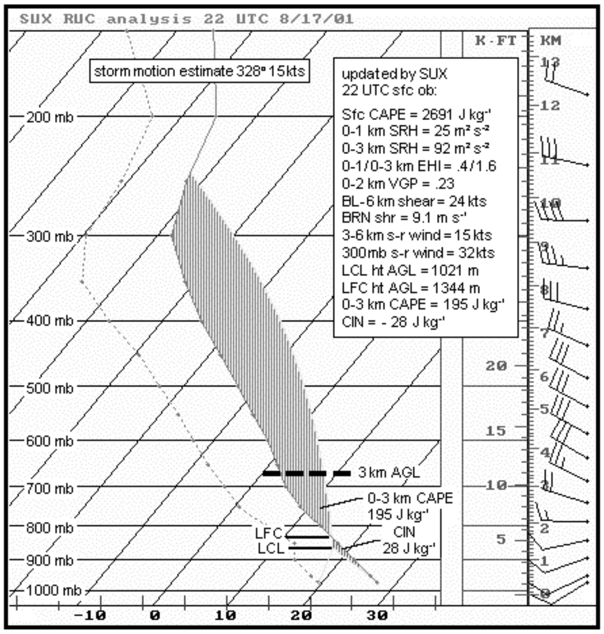

Figure 2. SkewT log*p* diagram showing RUC-2 analysis profile for Sioux City, Iowa at 22 UTC 8/17/01 modified by 22 UTC surface observation. Thermodynamic parameters are surface-based.

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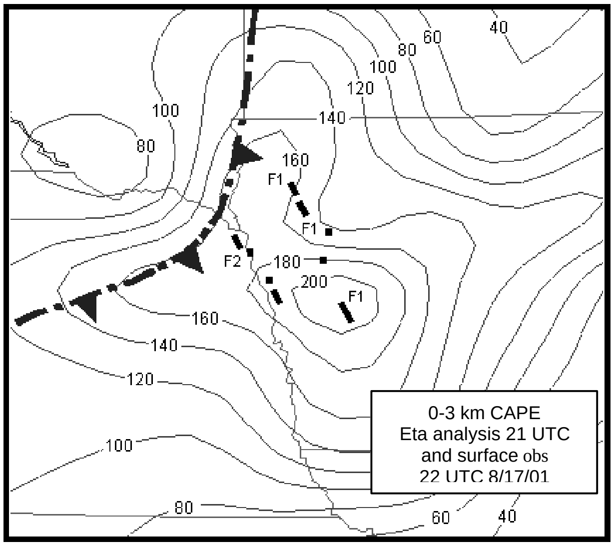

Figure 3. As in Fig. 1, except estimated surbace-based 0-3 km CAPE (20 J kg$^{-1}$ contours) for 22 UTC 8/17/01. Tornado tracks 2200-0130 UTC are indicated, F-scales greater than F0 labeled.

at 22 UTC. Observed surface winds remained southwesterly at Sioux City throughout the period 21 to 00 UTC, resulting in poor veering of wind with height and relatively weak deep-layer shear.

Notice the small CIN and large amount of surface-based low-level CAPE (Davies 2002, this volume) with the profile in Fig. 2. The Eta-derived 0-3 km CAPE field at 22 UTC (Fig. 3) also indicated an area of large low-level CAPE (160-200 J kg$^{-1}$), extending from Sioux City southeast through western Iowa.

Several storms formed on or near the boundary in the vicinity of the Nebraska/Iowa/South Dakota border between 21 and 22 UTC. The westernmost storm produced an F2 tornado at Jackson just west of Sioux City around 2240 UTC, and other tornadoes in extreme western Iowa (see Fig. 3 for tornado locations). Moving south-southeast, this storm tracked nearly 70 degrees to the right of the 0-6 km mean wind. Several other tornadoes occurred with storms in northwest Iowa, although these were rated only F0-F1 in intensity.

## 3. Myrtle Beach, South Carolina tornado case 7/6/01

This event was associated with an upper trough (not shown) that moved east-southeast through the Carolinas area during midday, along with a weak cool front (see Fig. 4) which was also moving slowly southeast. Other boundaries may have been involved, including a thunderstorm outflow boundary from morning convection over the Atlantic (also indicated in Fig. 4), and possibly a land/sea breeze boundary along the South Carolina coast.

Estimated fields of SRH and deep-layer shear derived from the Eta model (not shown) were relatively weak. Figure 5 shows the Eta analysis profile for Myrtle Beach at 18 UTC, updated by early afternoon surface data. This profile also suggests that SRH and BL-6 km shear values were not impressive, with SRH and deep-layer shear similar to the Jackson case.

In contrast to the vertical shear, 0-3 km CAPE was large (around 200 J kg$^{-1}$) as indicated in Fig. 5, along with small CIN and a low LFC height. The estimated 0-3 km CAPE field for early afternoon (not shown) also suggested a well-defined low-level CAPE maximum over northeast South Carolina and the Myrtle Beach area.

New convection developed near the intersection of the front and outflow boundary north of Myrtle Beach around 19 UTC. The westernmost cell moved into Myrtle Beach and produced an F2 tornado along the beachfront around 2015 UTC. Staying on or near the boundaries, at times the storm moved south-southwest, more than 90 degrees right of the 0-6 km mean wind.

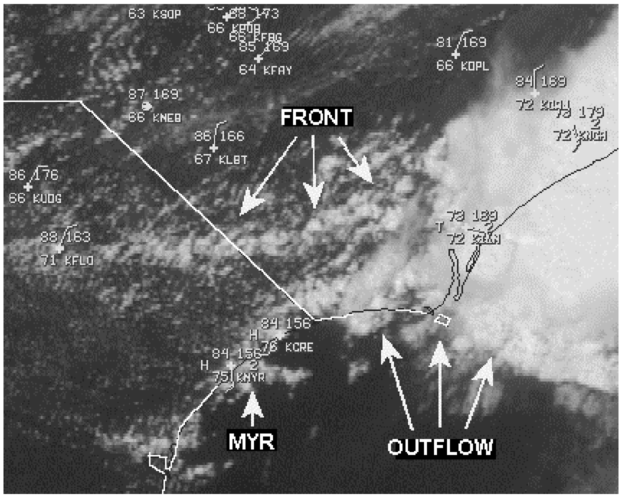

Figure 4. Visible satellite photo (courtesy Univ. of Wisconsin) at 18 UTC 7/6/01 with frontal and outflow boundary locations indicated by arrows. Myrtle Beach is also indicated ("MYR").

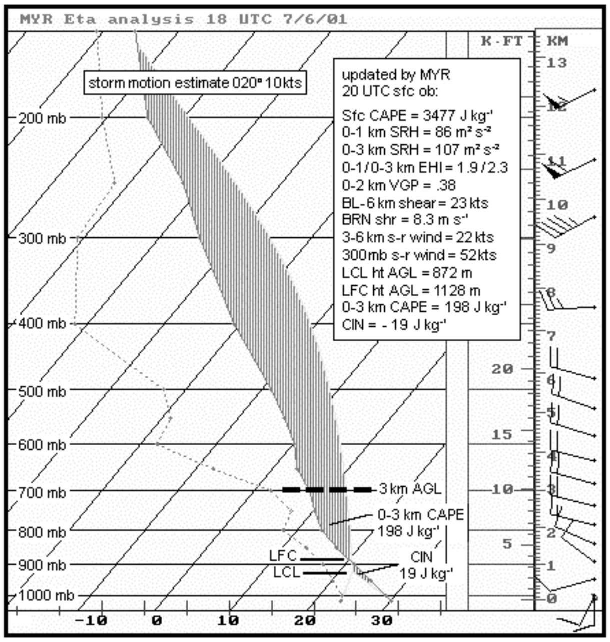

Figure 5. As in Fig. 2, except Eta analysis profile for Myrtle Beach at 18 UTC 7/6/01 modified by 18 UTC surface observation.

## 4. Jarrell, Texas tornado case 5/27/97

This event in central Texas, involving several tornadoes of strong or violent intensity, is well known and has been studied by several researchers. Magsig et al. (1998) found that the Jarrell tornado developed slightly east of a pre-existing northeast-southwest boundary, and more directly resulted from an interaction of a low-level radar-indicated circulation with a local southward-moving thunderstorm outflow boundary.

The large total CAPE (5000-7000 J kg$^{-1}$) and weak lower tropospheric flow (10 kts or less in the lowest 10,000 ft) have been well documented for this case (e.g., Magsig et al. 1998). But thermodynamic characteristics such as low-level CAPE have not been examined specifically. When modified for surface temperature and dewpoint close to the boundary, a special sounding (not shown) launched 40 miles east of the Jarrell storm by the TEXACAL 97 experiment (Biggerstaff et al. 1997) yields over 200 J kg$^{-1}$ of 0-3 km CAPE, using a near-surface parcel. Similarly, the Eta analysis profile for Temple, Texas at 18 UTC updated by observed surface data at the same site (Fig. 6) suggests large amounts of 0-3 km CAPE, a low LFC, and small CIN. Both profiles, along with Fig. 7 showing an Eta-derived depiction of the low-level CAPE field at early afternoon, suggest that low-level CAPE was quite large (200-300 J kg$^{-1}$) near the pre-existing boundary in central Texas.

Storms near the boundary moved toward the south-southwest, more than 100 degrees to the right of the 0-6 km mean wind, making this an <u>*extreme*</u> case in terms of both storm motion and thermodynamic factors. Nevertheless, comparing the Jarrell event to the earlier cases studied, three features are in common: a pre-existing boundary, large low-level CAPE, and strong rightward deviate storm motion on or near the boundary.

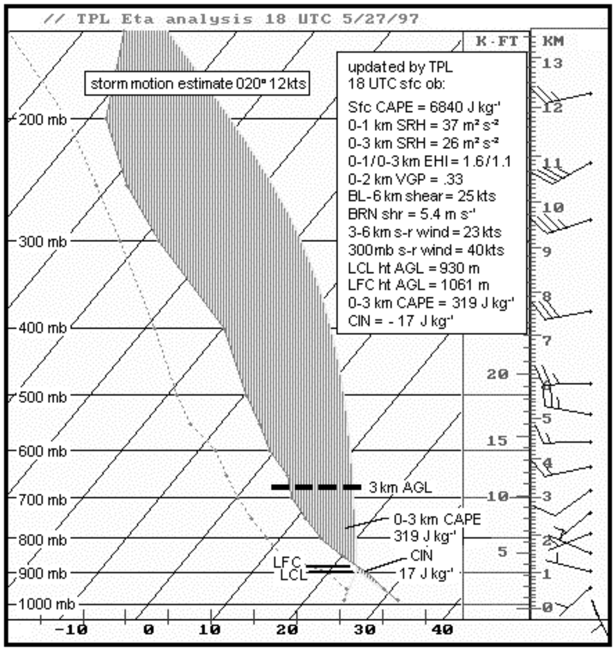

Figure 6 As in Fig. 5, except Eta analysis profile for Temple, TX at 18 UTC 5/27/97, modified by 18 UTC surface observation.

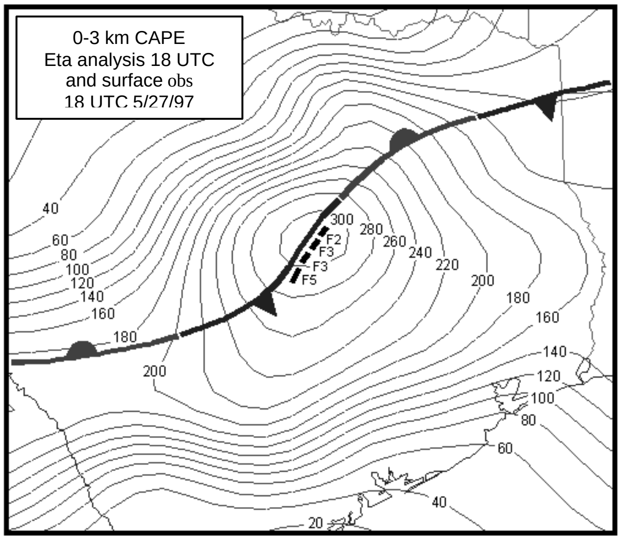

Figure 7. 0-3 km CAPE as in Fig. 3, except for 18 UTC 5/27/97 using Eta model analysis at 18 UTC merged with surface observations at same time. Stationary frontal wind shift boundary is heavy line with barbs. Significant tornado tracks 18-21 UTC are indicated, along with F-scales.

## 5. Discussion

The following features documented from this limited study may be useful in alerting short-term forecasters to the potential for significant tornadoes in shear environments of relatively benign appearance:

1) a pre-existing wind shift boundary, along which storms develop rapidly
2) large low-level CAPE (rapid positive buoyancy increase in low-levels) and small near-surface CIN
3) storm motion that remains on or close to the boundary, well right of the mean environment wind.

Such scenarios appear most likely in the warm season when larger total CAPE (e.g., > 2000-3000 J kg$^{-1}$) can also be present. The possible relevance of each of these features is discussed briefly below.

Boundaries have become increasingly recognized as an important enhancement factor in many significant tornado cases (e.g., Rasmussen et al. 2000). For the cases in this study, boundaries oriented in a general northeast-southwest pattern were present, but the role of the boundaries is not entirely clear. Given the relatively weak shear environments, it is tempting to focus exclusively on the "non-supercell" model of tornado development from Wakimoto and Wilson (1989) and Brady and Szoke (1989) that involves stretching of enhanced vertical vorticity by updrafts co-located with pre-existing boundaries. But, in the cases studied, it also appears that some of the tornadoes may not have occurred directly on the original pre-existing boundaries. Magsig et al. (1998) suggested that thunderstorm outflow was important in the Jarrell case. Radar study of specific outflow evolutions is beyond the scope of this study, but it is possible that new outflow boundaries were an additional factor in the cases examined, enhancing whatever horizontal and vertical vorticity was present in the local environments near the original boundaries.

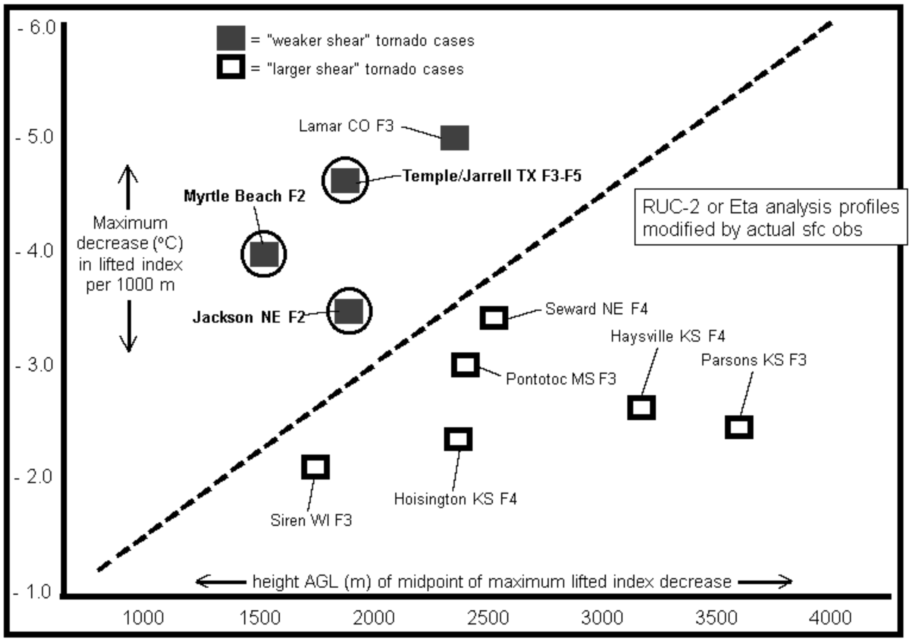

Figure 8. Scatterdiagram showing most rapid increase in buoyancy (decrease in surface-based lifted index across a 1000m layer in the vertical) plotted against elevation of that layer above ground (m) for model analysis profiles from several tornado cases 1999-2001 (labeled). Solid squares are “weaker shear” cases as defined in this study; the three cases circled are case studies in the text. Open squares are cases with larger shear more typically associated with significant supercell tornadoes.

Large low-level CAPE and associated small CIN and low LFC heights (Davies 2002, this volume) may also have been an important factor for these cases. Data from a climatology of observed soundings in the central plains (Bunkers et al. 2002, this volume) suggests that surface-based 0-3 km CAPE values approaching 200 $J\ kg^{-1}$ are rather large and occur relatively infrequently in the plains states. The cases examined in this study all involved low-level CAPE amounts of similar magnitude.

Regarding low-level buoyancy, it is interesting to view the estimated environments in terms of maximum rate of increase in positive buoyancy with height. Figure 8 shows several recent tornado cases using model analysis data blended with actual surface observations, including the three weaker shear cases from this study (circled solid squares) and the Lamar case studied by Hodanish and Davies (2002, this volume). The y-axis shows the maximum decrease in surface-based lifted index (increase in positive buoyancy) through a 1000 m layer located above the LFC, while the x-axis shows the location of the midpoint of that layer above ground. Cases located in the upper left ½ of the diagram have more rapid increases in buoyancy generally located closer to the ground than do cases in the lower right ½ of the diagram, suggesting potential for increased upward parcel accelerations and associated stretching in lowest levels. Notice how the weaker shear cases tend to reside in that part of the diagram, suggesting that this characteristic may be an important factor in significant tornado events occurring in relatively weak shear.

Brooks et al. (1994) and Thompson (1998) have shown the importance of storm-relative mid and upper tropospheric flow in storm environments capable of supporting supercell tornadoes. Stronger flow relative to the storm at these levels apparently helps to move precipitation downwind, reducing potential for low-level cold pooling and interference with the updraft, also increasing storm organization and longevity. Given the storm motion on or near a boundary in each of these cases (70 to 90 degrees or more right of the mean environment wind), the midlevel storm-relative flow was increased substantially. That may have been an important factor for storm persistence and organization not immediately apparent from the relatively weak deep-layer shear characteristics of the environments.

More research is needed regarding significant tornado events in relatively weak shear to learn about the relevance of these and other features to tornado development, and to help forecasters recognize some of these environments and features.

Additional information on this topic can be found on the author’s web site, http://members.cox.net/jdavies1/.

## 6. Acknowledgements

The author thanks Pete Wolf at NWS Wichita and Steve Hodanish at NWS Pueblo for their comments and input on this study.

## 7. Key references

Davies, J. M., 2002: On low-level thermodynamic parameters associated with tornadic and nontornadic supercells. Preprints, *21st Conf. on Severe Local Storms*, San Antonio, Amer. Meteor. Soc. (this volume).

Hodanish, S. and J. M. Davies, 2002: The 29 May 2001 Lamar, Colorado tornadic event. Preprints, *21st Conf. on Severe Local Storms*, San Antonio, Amer. Meteor. Soc. (this volume).

Magsig, M. A., D. W. Burgess, R. R. Lee, 1998: Multiple boundary evolution and tornadogenesis associated with the Jarrell Texas events. Preprints, *19th Conf. on Severe Local Storms*, Minneapolis, MN, Amer. Meteor. Soc. 186-189.

Rasmussen, E. N. , and D. O. Blanchard, 1998: A baseline climotology of sounding-derived supercell and tornado forecast parameters. *Wea. Forecasting*, **13**, 1148-1164.

Rasmussen, E. N., S. Richardson, J. M. Straka, P. M. Markowski, D. O. Blanchard, 2000: The association of significant tornadoes with a baroclinic boundary on 2 June 1995. *Mon. Wea. Rev.*, **128**, 174–191.

Thompson, R. L., 1998: Eta model storm-relative winds associated with tornadic and nontornadic supercells. *Wea. Forecasting*, **13**, 125-137.

Wakimoto, R. M. and J. W. Wilson, 1989: Non-supercell tornadoes. *Mon. Wea Rev.*, **117**, 1113-1140, 1989.