Synoptic Case Study of the Central Plains Mini-Supercells on 29 October 2000

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I. Introduction

During the afternoon of 29 October 2000 several small supercells developed in central and eastern Nebraska. Many of these supercells produced small tornadoes and minor damage. All of the tornadoes were spawned along a northward moving warm front associated with a strong area of low pressure over west central Kansas. As with many severe weather events in the Central Plains in fall, these supercells could be classified as mini-supercells. They were characterized by storm tops of less than 30,000ft, small horizontal dimensions, low dewpoints and dewpoint depressions, and very little electrical activity.

The implementation of the WSR-88Ds in the 1990's has helped lead to the distinction of these mini-supercells (Burgess et al. 1995). There have been several different papers presented where characteristics have been developed to recognize patterns favorable for their development, as well as their visual and radar characteristics. The purpose of this paper is to examine the changes that took place in the thermodynamic environment as well as the vertical shear structure between 1200 UTC 29 October and 0000 UTC 30 October. Through this detailed examination, the goal of this paper is to help the operational forecaster recognize this pattern that can produce these mini-supercells and associated tornadoes.

While there were some distinct differences in the 29 October event from other past mini-supercell events, but there were also some general synoptic similarities which can help to generalize one pattern favorable for mini-supercell development. Generally what mini-supercell events have in common is strong vertical and directional shear with relatively low to modest (generally less than 2000 J/Kg) amounts of convective available potential energy (CAPE). One way that each mini-supercell event is different is the way in which the thermodynamic environment becomes favorable for supercell development. Foster and Moller (1995) described CAPE values as low as 200 to 1500 J/Kg supporting mini-supercell development. Although 200 J/Kg is a low amount of CAPE, it must be remembered that this amount of energy is being converted into supercells that have the vertical extent of only one-half to two-thirds the size of large supercells (Davies 1993)

From past studies and observations of mini-supercells we can develop some general characteristics to identify these storms. Mini-supercells, due to the low equilibrium levels, have tops that are generally less than 30,000 feet, and are characterized by low amounts of electrical activity (Davies 1993). This includes both cloud-to-ground and cloud-to-cloud lightning, due in part to the low vertical extent. Much of the time they are characterized by maximum reflectivity values less than 50 dBZ, but have many of the same radar signatures as do larger supercells, such as hook echoes, weak echo regions, bounded weak echo regions, and mesocylones (Grant and Prentice 1996). The dimensions of mini-supercells are much smaller than larger supercells, and can average around 4nm by 8nm (Guerrero and Read 1993). Also, mini-supercells have been documented producing strong tornadoes (F2 or greater) as in the Wylie, Texas tornado in May 1993 (Foster and Moller 1995).

Through the examination of the conditions on 29 October, two conclusions were reached. The first was the mode in which the atmosphere became unstable and supported the development of severe convection. This was mainly through the movement of the mid level cold pool that was associated with the cold core upper level cyclone. The second point of interest is the vertical wind shear. This study found that it may be more useful to use a total shear vector in the 0 to 3 or 4 km range as a predictor of mini supercells instead of the widely used 0 to 6 km vector. For this study both the deep layer and low level total shear were analyzed, then converted to mean shear to get a better understanding where the strongest shear was occurring. In this case, the low level mean shear, both 0 to 2 km and 0 to 3 km were very strong on soundings from Omaha, Nebraska (OMA) and Topeka, Kansas (TOP), while the 0 to 6 km mean shear was relatively weak.

II. Synoptic

a. Upper Air

The long wave pattern on the morning of the 29 October was characterized by a long wave trough positioned along the west coast of the United States. A strong full latitude ridge was located from the Great Lakes south into the lower Mississippi Valley. In the eastern United States, a deep trough was located just off the New England coast (not shown). At 300 mb, the jet structure indicated a negatively tilted low ejecting out of the mean western US trough, which at 1200 UTC was located in western Kansas. A 35 to 40 ms^{-1} speed maximum was located in the base of the trough from western Oklahoma north into Kansas. Associated with the jet streak was a strong area of divergence, and widespread stratiform rain was located from northeast Kansas into eastern Nebraska (Fig. 1). At 500 mb (Fig. 2), a nearly vertically stacked negatively tilted closed cyclone was located in western Kansas. The ridge extended from the Great Lakes region south into the Gulf of Mexico. Also visible in Figure 2, a significant cold pool of -15 °C air was associated with the upper level low over western Kansas. A mid-level cyclonically curved speed maximum of 30 to 35 ms^{-1} extended from the base of the trough over northwest Texas into Western Oklahoma and then again in northern Kansas into southern Nebraska. This is also the case at 700 mb (Fig. 3) with the closed low and associated cold pool (0 °C) over eastern Colorado and western

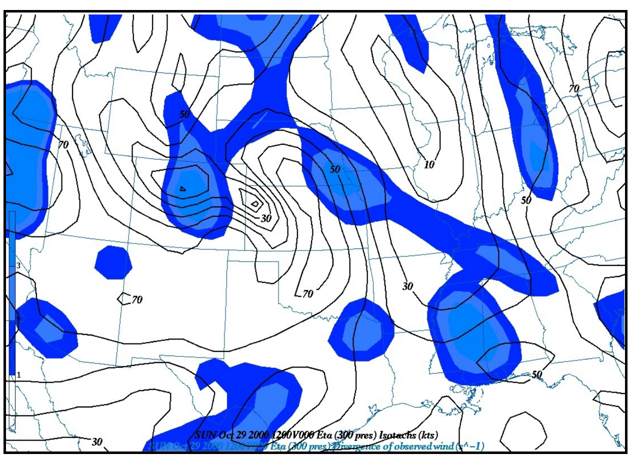

Figure 1. 1200 UTC 29 October ETA 300 mb initialization. Isotachs are the black contours labeled every 10 knots. Divergence is in the blue shading.

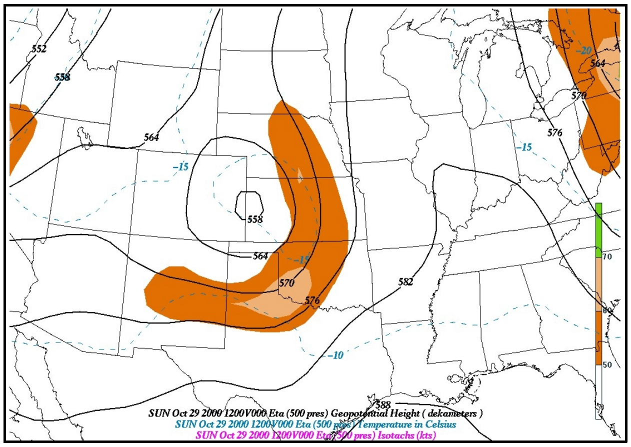

Figure 2. 1200 UTC 29 October ETA 500 mb initialization. Heights are in black with 60 meter contour intervals. Shading is isotachs, and temperatures in °C are contoured every 5 degrees.

Kansas, and a 25 ms^{-1} speed max oriented from northern Oklahoma north into southern Nebraska. At 850 mb (Fig. 4), a warm front extended east and southeast from the closed low over western Kansas. The warm front was positioned across southern Kansas east into northern Arkansas. Significant low level moisture with 8 °C dewpoints at 850 mb was being advected across the warm front on a 20 to 25 ms^{-1} low level jet.

b. Surface

The subjective surface analysis (figure 5) from 1200 UTC 29 October depicted high pressure over the Great Lakes with a broad easterly flow of cool moist air into the northern high plains. A 1002 mb surface low was located over far southwest Kansas with a dryline extending south and east from the low across western Oklahoma and northwestern Texas. A warm front extended north and then east from the low and was along a line from near Dodge City, KS to Hill City, KS northeast to the Nebraska border. The warm front was then positioned southeast through TOP and into southwest Missouri near Joplin. The warm sector was characterized by upper 50s °F to lower 60s °F dewpoints. Surface temperatures were generally in the 60s °F south of the warm front, with cooler 40s °F and 50s °F located to the north of the warm front. Morning soundings from OMA and TOP (Fig. 6a and 6b) were indicative of the atmosphere north of the warm front. These soundings indicated strong warm air advection (WAA) throughout the vertical and nearly moist adiabatic lapse rates. The 1200 UTC sounding from Oklahoma City, OK (not shown) did indicate the presence of a mid-level dry intrusion and steeper mid-level lapse rates, but exhibited little instability due to the very limited low level moisture south of the 850 mb warm front.

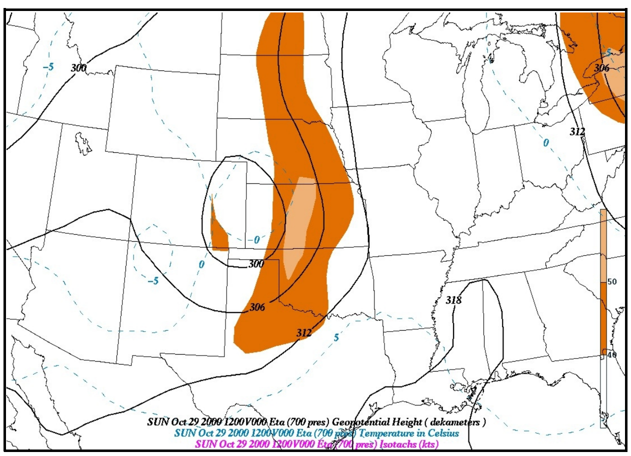

Figure 3. Save as figure 2, but for 700 mb.

III. Thermodynamic Set Up

As with past studies on mini-supercell events, there was a vertically stacked closed low present as well as a significant cold pool aloft (Davies 1993, Goetsch 1988, Murphy and Woods 1992). This cold pool aloft provided the key ingredients for destabilization on 29 October. Two past studies on cold core mini-supercells outbreaks done by Goetsch (1988) and Davies (1993) described mini-supercells that developed in the warm sector to the southeast and east of the surface low

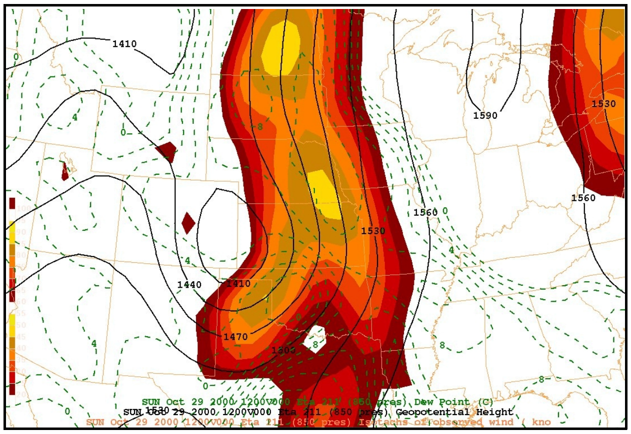

Figure 4. 1200 UTC 29 October ETA 850 mb initialization. Heights are in black contour labled every 30 meters. Shading are isotachs. Dewpoints are contoured every 2 °C in blue.

pressure system. On 29 October there was very little development in the warm sector. Most of the development, and all of the severe weather, was along the warm front and on the cool side of this boundary.

Special 1800 UTC soundings were done at both OMA (not shown) and TOP (Fig. 7a), and indicated that Omaha continued to be north of the warm front and was still characterized by low lapse rates and a moist adiabatic temperature and moisture profile. Conversely, TOP sounding indicated the warm front at both the surface and 850mb had moved north of the area. The sounding indicated significant mid-level drying and some steepening of the 700 to 500 mb lapse rates due to the advection of the cold pocket associated with the mid-level cyclone. This sounding is convectively unstable with the most unstable CAPE of 573 J/Kg, Total Totals of 51, and a lifted index of -5 °C. Modifying the 1800 UTC TOP sounding to account for the temperature and dewpoint from the surface at 1900 UTC (using the 1900 UTC observation from Grand Island, Nebraska) the sounding becomes moderately unstable (Fig. 7b) with a most unstable CAPE of 1133 J/Kg, Total Totals of 51, and a lifted index of -6 °C.

Murphy and Woods (1992) using

$$WMAX = (2*B+)^{1/2} \qquad (1)$$

where WMAX is the maximum vertical velocity and B+ is the net positive energy, showed a damaging tornado can occur with as little as 47 ms^{-1} of vertical velocity. Using the modified Topeka sounding, we can compute a maximum vertical velocity of 48 ms^{-1}. Although this is much weaker than the 70 ms^{-1} found by Rasmussen and Welhelmson (1983) for southern plains tornadic supercells, it must be remembered that this convection is much shallower than deep supercells which can extend to 60 thousand feet.

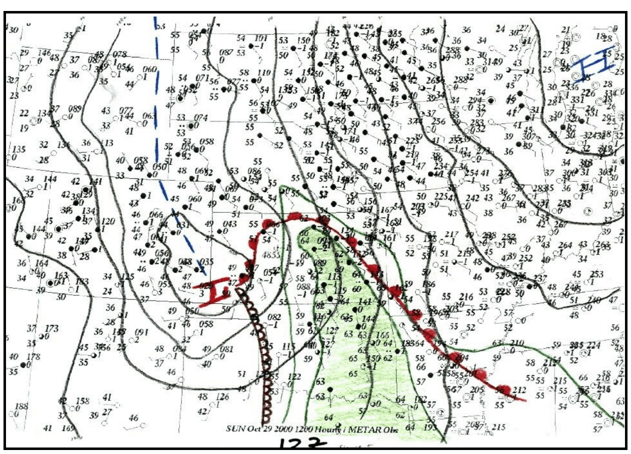

Figure 5. 1200 UTC objective surface analysis.

Anticipating the amount of instability, as in this case, can be very difficult. In a similar case, Murphy and Woods (1992) when studying a damaging mini-supercell tornado in the Atlanta, Georgia area, noticed when examining a proximity sounding that the wet-bulb temperature when overlaid on the sounding, crossed the saturated adiabats toward the left with

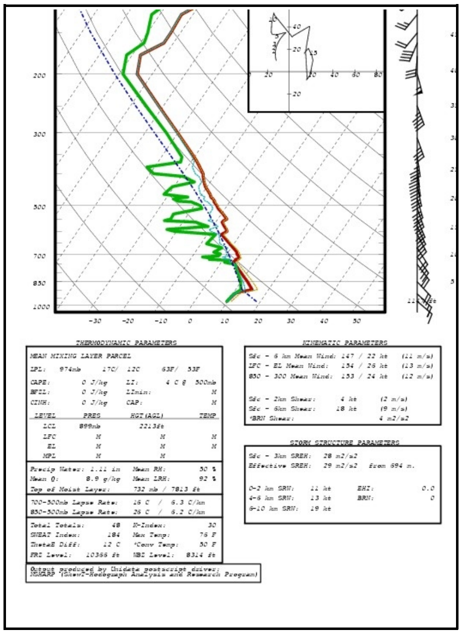

Figure 6a. 1200 UTC observed sounding.

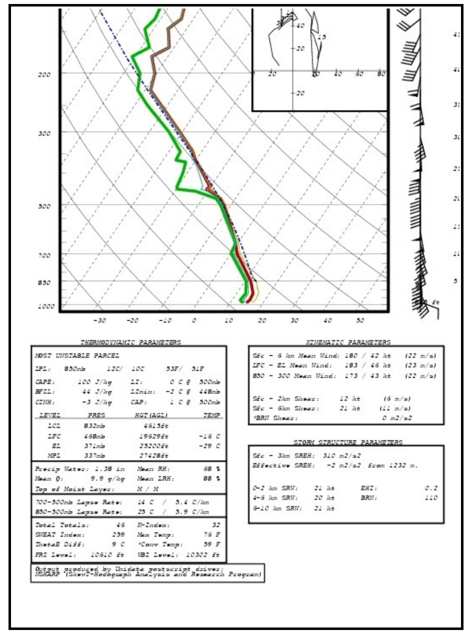

Figure 6b. 1200 UTC observed TOP sounding.

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sing height. This would indicate that this layer is convectively unstable if the layer is lifted to

saturation. The same thinking can also be applied to equivalent potential temperatures (θ_e) surfaces. If the (θ_e) surfaces decrease with height, then that layer can become unstable if lifted to saturation. Looking at a Eta model time height plot for Grand Island, Nebraska (Fig. 8) we can see there is potential instability since the theta-E surfaces decrease between the surface to about 500 mb.

This layer was lifted to saturation and did become convectively unstable. The lift was provided from the upper tropospheric jet, and the associated induced low level frontal circulation. Also overlaid in Fig. 8 are isotachs. At 1800 UTC an upper level jet of 25 to 30 m/s^{-1} was forecasted to induce a low level jet of 30 to 40 kts as it crossed the surface warm front in south central Nebraska. The divergence and upward vertical motion associated with the upper and lower tropospheric jets was discussed by Bluestein and Thomas (1984) and Johns (1993). Their studies found that the "strong dynamic pattern", as discussed by Johns (1993), could be enough to release potential instability. An additional time height from the same Eta model run (not shown) reveals strong deep vertical motion beginning during the late morning and reaching a maximum around 0000 UTC. This omega field was likely due to the strong upper level jet, and induced lower tropospheric jets crossing the surface boundary, and thus provided the needed lift to allow this layer to become saturated and convectively unstable.

The presence of deep moisture on 29 October contributed to the possibility of tornadoes since this converted to a lifted condensation level of 775 meters on the modified 1800 UTC sounding from TOP (Edwards and Thompson 2000). In addition to the low condensation levels due to the deep moisture, Gilmore and Wicker (1998) showed that the combination of strong low level shear and a lack of a low level dry intrusion can lead to a more sustained supercell. Here the mid level dry intrusion, which was represented at 700 mb with near 10 percent relative humidity from northern Oklahoma into southern Kansas at 1800 UTC, is south of the surface and 850 mb warm fronts (Fig.

9). Thus the lack of a mid level dry intrusion, coupled with the strong low level shear, led to an increased potential for tornadoes.

Thus a combination of strong lift, due to the coupled jet structure, on a potentially unstable layer of the atmosphere, and the movement of the cold pool associated with a mid-level closed cyclone were responsible for the limited destabilization and release of that instability which allowed for the development of the mini-supercells. Figure 10 shows the CAA from western Kansas south into western north Texas at 1200 UTC. This area of cold air advection (CAA) was able to lift to the northeast through the morning and afternoon hours providing strong cooling above the boundary layer. When comparing the 1200 UTC TOP sounding (Fig. 6b) with the 1800 UTC sounding (Fig.7b) the significance of the CAA is visible in the degree of cooling which took place during the six hour period (table 1 below).

Time UTC	TOP 500 mb °C	OMA 500 mb °C
12	-12.1	-13.1
18	-16.5	-14.1
Total Cooling	-4.4	-1

IV. Shear Profiles

As discussed above the vertical shear was characterized by strong low level shear. Many past studies have also looked at the shear near mini-supercells. In virtually all cases looked at, shear was either moderate or strong (i.e. inflow > 20kts and mid-level winds > 30 knts). Looking at the isotachs at each significant level on 29 October, there was a strong jet maxima present. Research indicates tornado development is typically associated with a

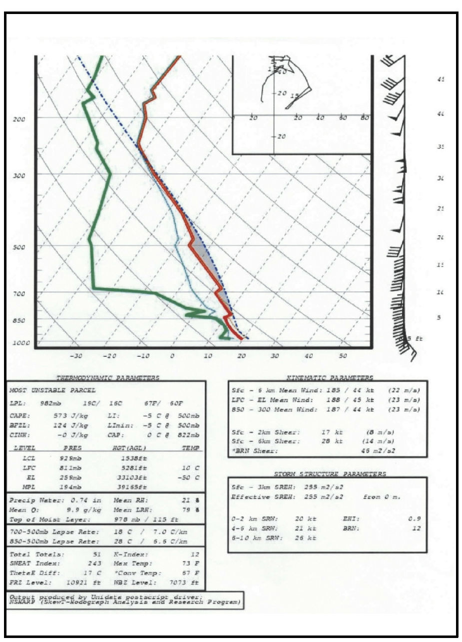

Figure 7a. 1800 UTC observed TOP sounding.

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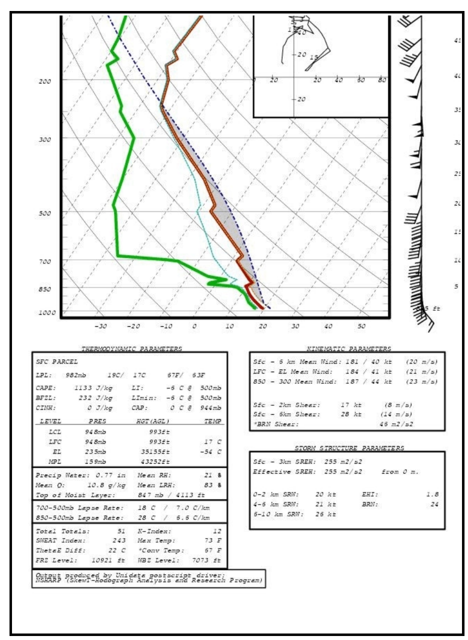

Figure 7b. 1800 UTC modified TOP sounding.

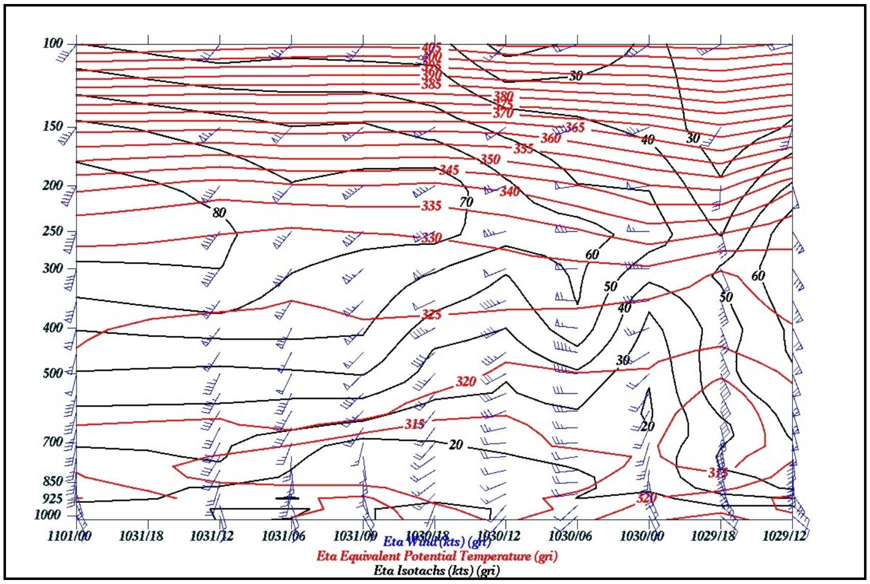

Figure 8. Time height plot from 1200 UTC ETA model run. Potential surfaces are contoured every 5 $^{\circ}$ K, isotachs are in black labeled every 10 knots, and wind barbs are in knots.

ptic pattern where the coupled upper and lower tropospheric jets lead to strong vertical wind shear in the warm sector. Looking back at Figures 1 and 4, as well as the time height plot for Grand Island, Nebraska (Fig. 8), we can see the upper level jet is crossing the 850 mb warm front and extending into central Nebraska. This is also directly above the low level jet and moisture axis as seen in figure 4 from the mid Mississippi Valley northwest into the western high plains.

Davies (1993) found that the shear profiles in the mini-supercells in his study were characterized by significant 0 to 3 km storm relative helicity (SRH) of 327 m^2s^2, strong 0 to 2 km storm relative inflow of 21 kts, and strong 3 to 6 km mid-level winds of 48kts. This is fairly representative of most other studies as well, such as Murphy and Woods (1992), Geotsch (1988), Vescio et al (1993), Stalker and Knupp (1993), and Foster and Moller (1995). In this case, although the 0 to 6 km total shear appeared strong, 66 kt on the 1800 UTC TOP sounding, a much different picture is presented when this is converted to mean shear. Mean shear from Rasmussen and Wilhelmson (1983) is defined as the length of the hodograph divided by the depth of the hodograph. In this case the 0 to 6 km mean shear was 11.7 kts/m, but the 0 to 3 km mean shear was 13.3 kts/m. This implies that although there was certainly strong shear, most of the shear is found in the lowest 3 km of the atmosphere. Since mini-supercells have depths generally equal to or less than 30,000 ft, a shallower shear depth of 0 to 3 km or 0 to 4 km might be more representative of the local storm environment.

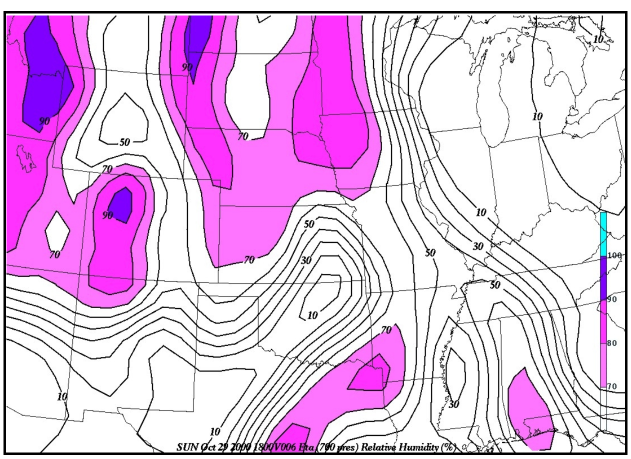

Figure 9. 1200 UTC ETA model forecast valid 1800 UTC 29 October indicating relative humidity. Contours are every 10 percent, and shading represents values greater than 70 percent.

Looking at the wind profile in figure 7b, there was little directional shear in the lowest 0 to 3km. Storm motion computed from this sounding is 180 degrees at 24 kts and yields 269 m^2s^2 0 to 3 km SRH. Although this is in the range found by Rasmussen and Blanchard (1998) to support supercells and tornadoes, the lack of low level directional turning would have limited the tornado potential. So there needed to be an additional mechanism to increase the directional shear in the 0 to 3 km range to support tornadogenisis.

That mechanism here is the warm front, which likely played a crucial role in mesocyclone development. The idea that interaction with a boundary can lead to a local increase in SRH is not a new concept, Davies-Jones et al. (1990) showed that deviant storm motion along and near fronts can be crucial for mesocyclone development. Also Markowski et al. (1998) found during the 1995 field experiment, Verifications of the Origins of Rotation in Tornadoes, that 70 percent of significant tornadoes were associated with pre-existing boundaries. Although boundary interaction can reasonably be assigned to all tornadic supercells (either with a pre-existing boundary or the combination of the forward and rear flank downdrafts), it is especially true in this case, where not all the factors support low level mesocyclone development and tornadogenisis. In Figure 11 the warm front at 1900 UTC is into central Nebraska. Overlaid on the surface map is triangles depicting where tornadoes were reported between 1800 UTC and 2100 UTC. Strongly backed surface winds along and north of the warm front allowed for strong low level veering of the low level wind profile. Further modifying the 1800 UTC TOP hodograph for conditions closer to the warm front in central Nebraska, would yield a 0 to 3 km SRH of 389 m^2s^2 (not shown). This would strongly point to tornadic supercells along the warm front.

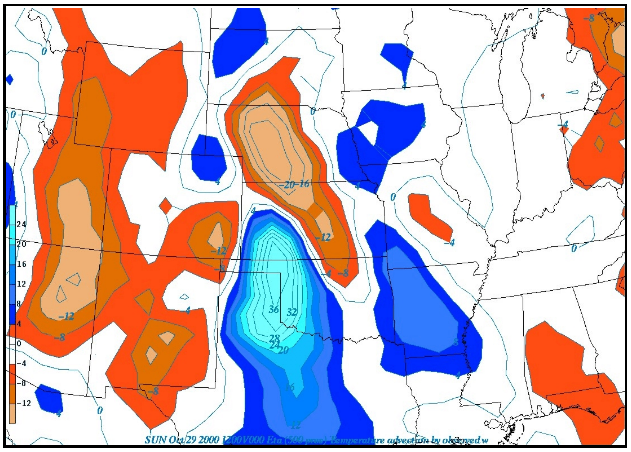

Figure 10. 1200 UTC ETA forecast 12 hour temperature advection valid 0000 UTC 30 October. CAA indicated in blue, and WAA indicated in red. Contours are labeled every 4 °C. Shading represents values greater than, or less than 4 degrees.

The interaction of the warm front with the mini-supercell activity played a crucial role in the development of tornadoes on 29 October. Since the warm front in this case played the role of a low level shear axis for thunderstorms and associated updrafts to become co-located, may give some reasoning to the lack of strong mid-level rotation, and a descending mesocyclones on local radars on 29 October 2000. This has also been seen in western high plains tornadoes not associated with supercells (Wakimoto and Wilson 1989).

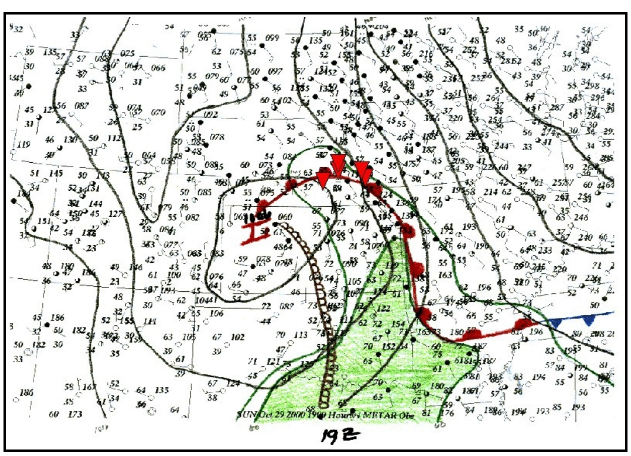

Figure 13. 1900 UTC objective surface analysis. Red triangles denote tornado occurrences between 1800 and 2100 UTC 29 October.

V. Conclusion

On 29 October 2001 several mini-supercells develop in central and eastern Nebraska along a northward moving warm front. These mini-supercells spawned several weak tornadoes that were responsible for minor damage during the afternoon. These mini-supercells developed in association with a ejecting negatively titled closed low. All of the tornadoes developed along a northward moving warm front due to the local increase in SRH near the boundary.

Using this case, as well as looking at past studies, this paper has brought together some basic characteristics of mini-supercells, and identifies one additional synoptic pattern favorable for their development. There have been several case studies done in recent history where different synoptic situations have been presented that produced mini-supercells. Although all these patterns have some differences, there are some similarities that relate the patterns, such as limited instability and strong low level wind shear. This case is interesting in that the 0 to 6 km mean shear was not strong, and the vertical wind profiles were very unidirectional in the lowest 0 to 3 km south of the warm front. This case suggests that due to the limited vertical extent of mini supercells, a smaller shear vector of 0 to 3 or 4 km may be more representative of the deep layer shear than 0 to 6 km. Supercells were able to develop due to the local increase in instability, and were able to produce tornadoes as they crossed the warm front which locally increased the low level directional turning and increased values of SRH, and also provided a local source of vorticity. Although at first look, most of these cases do not appear like classic plains supercell outbreaks. The forecaster must look closely for sources of instability in a environment characterized by strong low level shear. Although this was not a significant tornado outbreak, any tornado has the potential to have significant impact. It is also important to remember that although these supercells due not have the classic visual or radar appearance as larger supercells, these are no less dangerous and should be taken seriously by the public and the warning forecaster.

Here the source of instability was differential temperature advection as the cold pool associated with the mid level closed low moved into Nebraska during the afternoon on 29 October. Looking at area soundings this instability was not readily apparent, but modifying soundings for local environmental conditions can lead to a better understanding of the mesoscale environment. In addition to the cold pool aloft leading to an increase in instability, the dry intrusion over northern Oklahoma into southern Kansas at 1800 UTC on 29 October was positioned to the south and east of the surface and 850 mb warm fronts. Thus deep low level moisture was maintained over central and eastern Nebraska, and contributed to the low lifted condensation levels. Updrafts would have experienced little dry air entrainment, and this may have contributed to a sustainable low level mesocyclone. With deep low level moisture and strong low level wind shear present, downdrafts were less likely to undercut and weaken the updraft of thunderstorms.

Continuing cases studies about mini-supercells have led to a better understanding of the environment that support their development. Future research can hopefully build a climatological database of mini-supercells. This would include, the time of year they are likely to occur, and for what area of the county this would effect. This will also help to better define the patterns that support their development, and will help the forecasters ability to anticipate storm structure and type.

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