P3.2 Environmental and Synoptic Conditions Associated with Cool Season Strong and Violent Tornadoes in the North Central United States

Mark F. Britt* and Fred H. Glass

NOAA/National Weather Service Forecast Office
Saint Charles, MO

1. INTRODUCTION

While tornadoes can often occur during the cool season over the southern United States, they are relatively uncommon over the north central part of the country. A previous analysis by Britt and Glass (2000 – hereafter BG00) indicated that only a quarter of the strong (F2-F3) or violent (F4-F5) tornadoes that occur annually in eastern Missouri and southwest Illinois happen during the late autumn and winter months. However, when tornadoes do occur during these months, nearly half of them are either strong or violent. This is problematic for operational meteorologists as these infrequent events have a greater potential to cause damage and injury.

This study further expands the area previously identified in BG00 to include the north central United States (Fig. 1). The area encompasses the northern and central Great Plains, the Middle and Upper Mississippi River Valley, the Lower Ohio River Valley, and the western Great Lakes. The cool season is defined as November 16th through the end of February. An examination of the weeks before and after these dates indicates a greater frequency of tornado occurrence. This suggests these periods are more typical of the transition seasons of autumn and spring when there is a higher occurrence of tornadoes. Tornado reports were gathered using Severe Plot (Hart and Janish, 1999). A total of 43 strong and violent tornadoes were identified on 18 separate days during the period from 1979-2005.

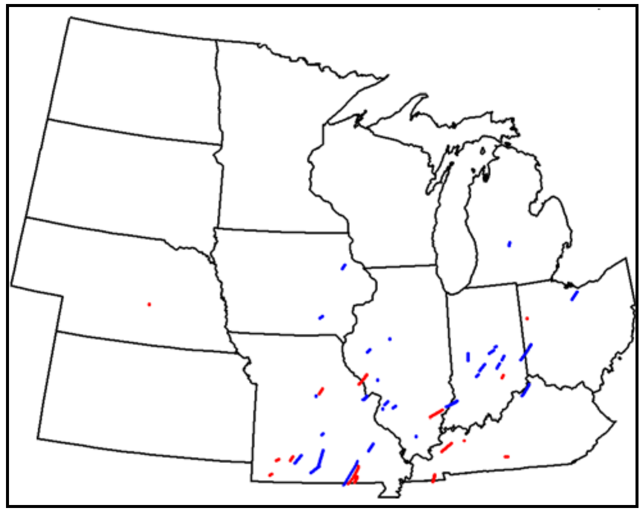


Fig. 1. Map of the tornadoes included in the study and the area of study (north central United States). Environmental parameters were calculated from the tornadoes highlighted in red.

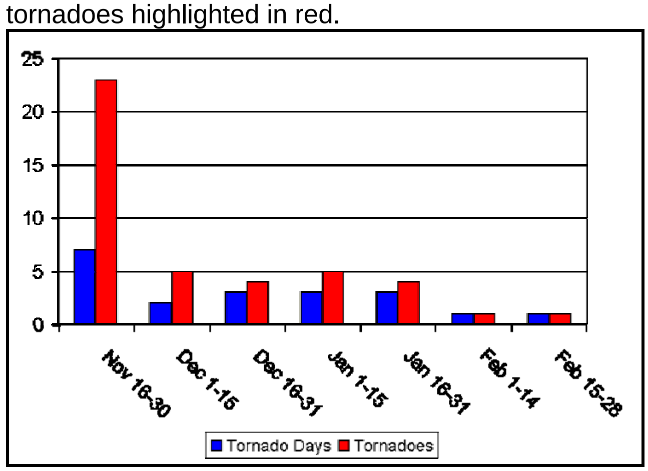


Fig. 2. Semi-monthly distribution of strong and violent tornadoes (1979-2005).

2. CLIMATOLOGY

The greatest occurrence of tornadoes and tornado days in this dataset is during the last half of November (Fig. 2). The other periods have a more even distribution with February having the least occurrence. Strong and violent tornadoes in the cool season tend to happen from mid afternoon into the early evening, much like they do at other times of the year (Fig. 3). However, they have also occurred during the late evening and overnight hours. BG00 did note that several violent tornadoes in their dataset occurred during these late hours. One of the most memorable St. Louis tornadoes was a F4 that occurred on February 10, 1959 at 1:40 a.m. resulting in 21 fatalities and 345 injuries.

**Corresponding author address: Mark F. Britt, NOAA/ National Weather Service, St. Charles, MO. E-mail: Mark.Britt@noaa.gov

3. ENVIRONMENTAL DATA

The period of study is from 1979 to 2005 to take advantage of the 32km resolution North American Regional Reanalysis (NARR) dataset (Mesinger et al.

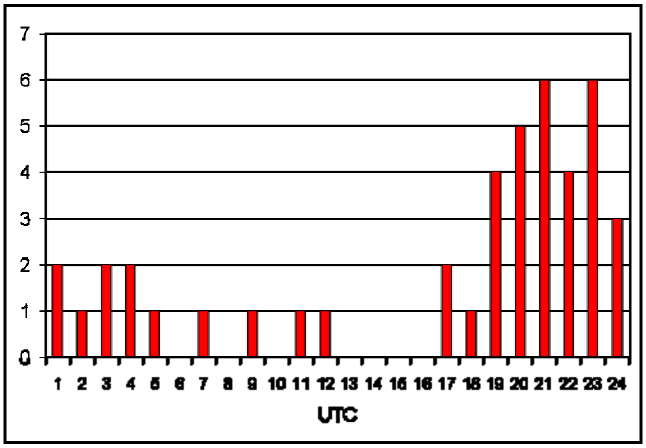
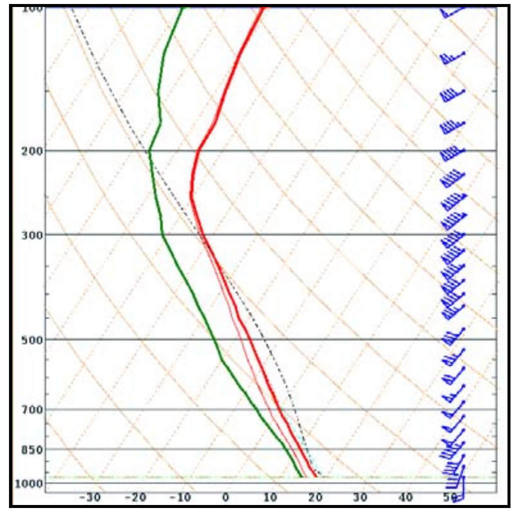
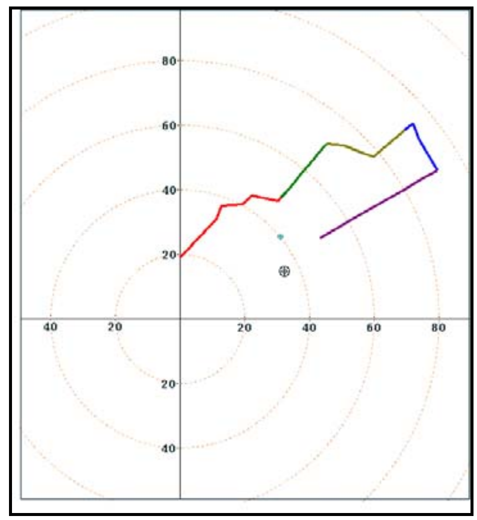


Fig. 3. Hourly distribution of strong and violent tornadoes (1979-2005).



a.



b.

Fig. 4. Composite Skew T (a.) and hodograph (b.) of the 18 soundings.

2006). The National Centers Advanced Weather Interactive Processing System Skew T Hodograph Analysis and Research Program (NSHARP) software (Hart et al., 1999) was used to extract representative soundings from the NARR dataset from locations in close spatial and temporal (nearest 3 hour) proximity to the tornadoes. Only one sounding was produced per day, except on one day when there was a separation of more than six hours between individual tornadoes. One case where tornadoes occurred in an environment where the most unstable parcel in the lowest 300 mb possessed less than 100 J/kg of Convective Available Potential Energy (MUCAPE) was excluded. It is believed that theses cases probably exhibited greater instability; however the spatial extent was not captured in even a relatively high resolution dataset like the NARR. An examination of plan view maps also showed diminished MUCAPE in areas coincident with where the NARR generated precipitation in its quantitative precipitation forecast fields. A total of 18 soundings were available for analysis. Thermodynamic and kinematic parameters currently deemed important to severe storm and tornadic environments were computed for each of the soundings.

3.1 *Composite Sounding*

The temperature, dewpoint, wind speed and wind direction from every 50 mb (starting at either 975 or 950mb up to 100 mb) was extracted from each of the 18 soundings generated by NSHARP. The mean values at each level were then used to create a composite skew-T and hodograph. The skew-T (Fig. 4a) depicts a sounding with a relatively moist lower atmosphere, a small positive area (CAPE), and a low equilibrium level. Approximately two-thirds of the CAPE lies below 500mb, the level typically used to compute the Lifted Index (LI). The hodograph (Fig. 4b) shows some veering of the winds from south to southwesterly in the lowest kilometer. The winds above one kilometer are generally southwesterly, unidirectional, and increase in speed with height.

3.2 *Thermodynamic Parameters*

CAPE values in this dataset are much lower than those found in previous studies that contain events year round, namely Thompson et al. 2003 (hereafter T03) that used RUC2 analysis, and Craven and Brooks, 2004 (hereafter CB04) that examined a large set of observational soundings. Eighty percent of our cases have mean parcel (1000-900mb) CAPE (MLCAPE) values that fall between 36 and 780 J/kg, with a median value of 257 J/kg (Fig. 5). These values are nearly tenfold lower than either T03 or CB04. MUCAPE values are larger than the MLCAPE, with 80 percent of the cases falling between 151 and 1304 J/kg, and a median value of 424 J/kg. It is thought that these lower numbers are possibly a reflection of the NARR limitations discussed in Section 3. Britt and

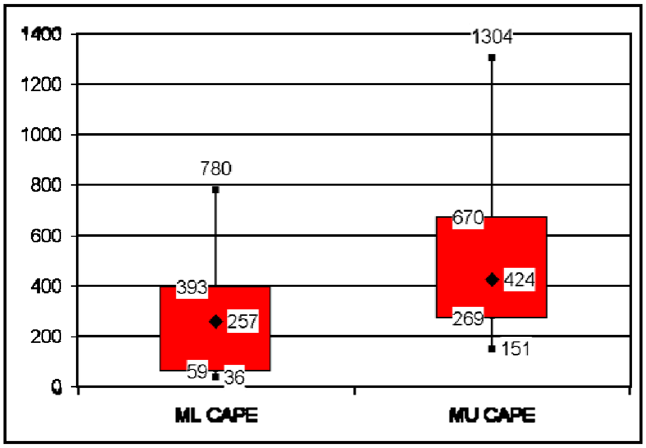


Fig. 5. Box and whiskers plot with values of MLCAPE and MUCAPE (in J/kg). The top and bottom of each box represents the 75th and 25th percentiles, respectively, and the diamond is the median value. The vertical lines extend upward to the 90th and downward to the 10th percentiles.

Glass (2005) in a similar study using a small dataset of modified observed soundings found 80 percent of the MLCAPE values between 262 and 1596 J/kg, with a median value of 559 J/kg.

The LIs are indicative of a weakly unstable environment, with the median values of ML and MU being only -0.8°C and -1.9°C respectively (Fig. 6). These numbers are derived using the traditional method of comparing the lifted parcel to the 500mb temperature. However, when calculating the minimum value of LI for the sounding, the median ML LI is -2.1°C and the median MU LI is -3.2°C. The height that the minimum LIs are calculated from are almost always found below 500mb, with the 90th percentile for both the ML and MU being 500mb, and the 10th percentile at 700 mb (Fig. 7). This finding goes along with the shallowness of the positive area seen in the composite sounding in Figure 4.

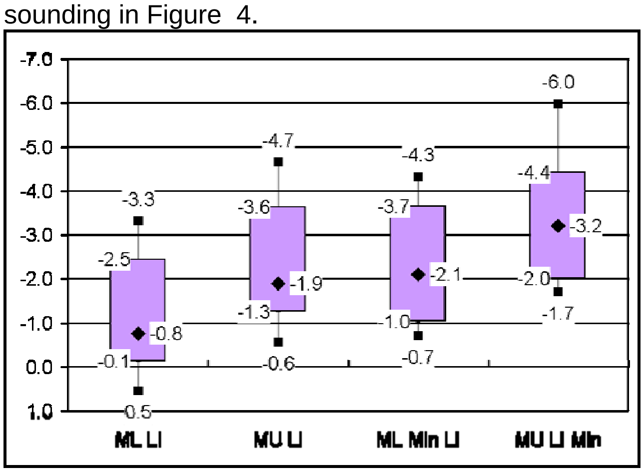


Fig. 6. Same as Fig 5., except for ML LI, MU LI, ML Min LI, an MU Min LI (in °C).

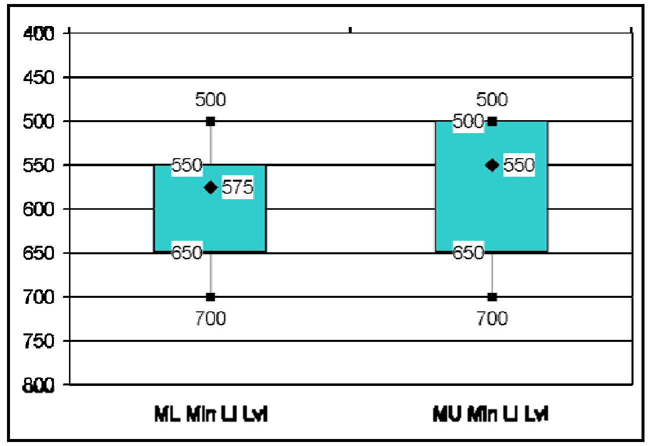


Fig. 7. Same as Fig 5., except for ML and MU Min LI Levels (in millibars).

Lifting Condensation Level (LCL) is often used as a proxy for low level moisture availability. Higher boundary layer moisture is thought to aid significant tornado development in an otherwise conducive environment. Eighty percent of ML LCLs fall between 657 and 1086 m, with a median value of 922 m (Fig. 8). These values are slightly lower than T03 and comparable to CB04. The lower values in this dataset reflect higher relatively humidity usually found in the boundary layer during cool season, extratropical storms. The average dewpoint depression in the lowest model level in this dataset is only 3.4°C

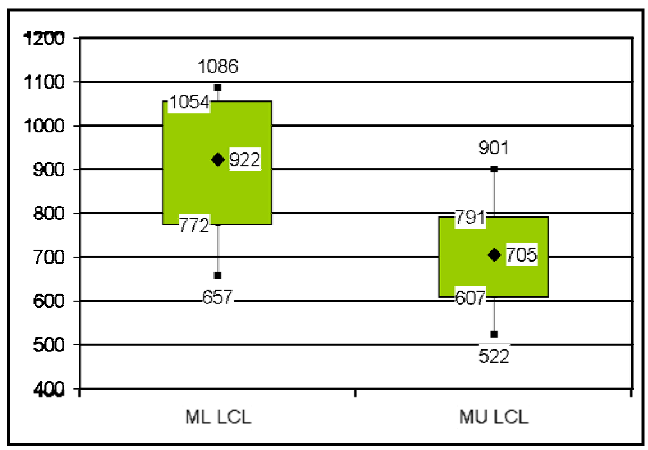


Fig 8. Same as Fig 5., except for MLLCL and MULCL (in meters).

3.3 *Wind Shear Parameters*

The magnitude of the bulk shear vector was calculated for three layers (Fig. 9). Eighty percent of the cases had values between 9.4 and 20 m/s in the lowest kilometer, with a median value of 14 m/s. The median value of shear magnitude in the lowest three kilometers is 22 m/s, with a spread of only 4 m/s for the middle 50%. Both the median value (34 m/s) and the 10th percentile (26.5 m/s) value of deep layer shear (0-6km) is well above the accepted levels (~20 m/s) thought needed for supercell convective modes in a given environment (Weisman and Klemp, 1982). Both of the 0-1 and 0-6km values are noticeably higher than in T03 (24.5 m/s in 0-6km, 9.8 m/s in 0-1km) and CB04 (~12 m/s in the 0-1km).

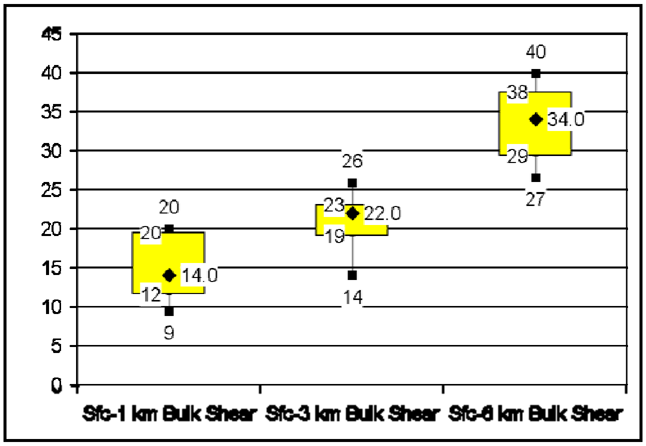


Fig 9. Same as Fig 5., except for shear vector magnitude (in m/s).

Storm motion was computed from the sounding using the method described by Bunkers et al. (2000). Storms move rapidly with a median storm motion from 230° at 24 m/s. Storm relative helicity (SRH) was then computed using the storm motions from the 18 individual cases in 0-1 and 0-3 km layers. Eighty percent of the cases had 0-1km SRH values between 71 and 302 m^2s^{-2}, with a median value of 176 $m^2 s^{-2}$ which is comparable to T03. The values of 0-3km SRH are only slightly higher than in the 0-1km layer (Fig. 10). This suggests that the greatest amount of SRH is in the lowest kilometer.

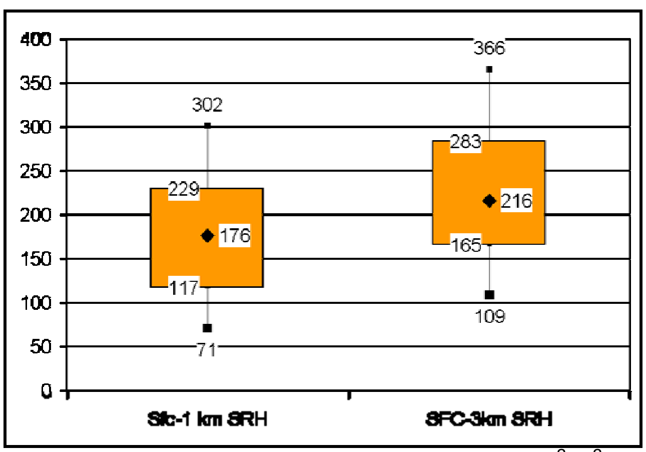
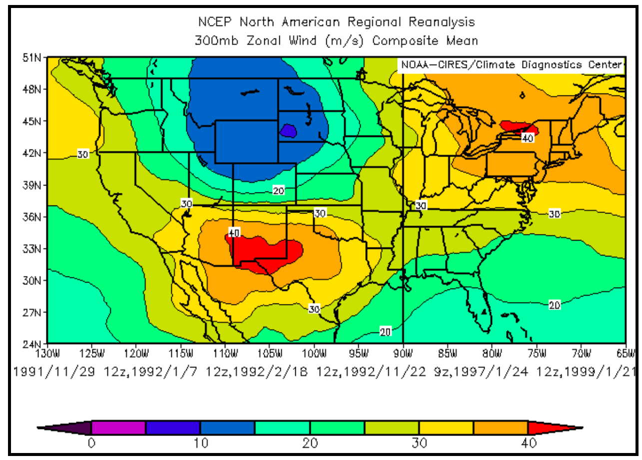


Fig. 10. Same as Fig. 5, except for SRH (in $m^2 s^{-2}$).

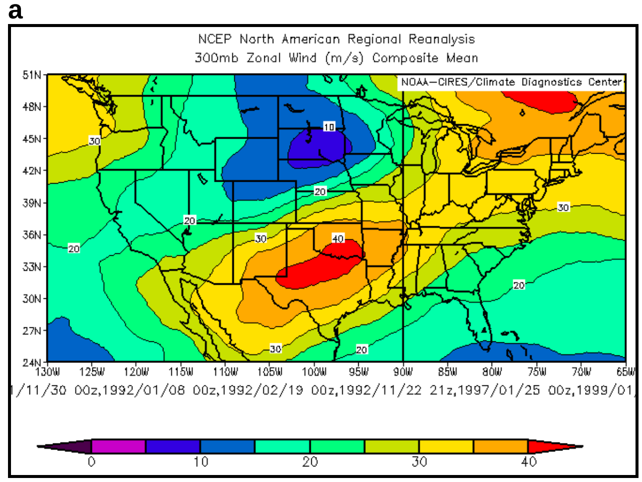
4. SYNOPTIC CONDITIONS

Composites of synoptic features were generated from the NARR dataset using the NOAA-CIRES Climate Diagnostics Center web site (http://www.cdc.noaa.gov/). The composites were created using the same dates and times used for the environmental parameters. Images were also generated for the twelve hours preceding tornado occurrence in an effort to document the short term evolution of the large scale environment.

The 300mb zonal wind (Fig. 11) suggests a coupled jet structure with one jet streak rounding the base of a central U.S. trough and a second over the northeastern U.S. This implies increased upper level divergence in the area were the tornadoes develop. The 500 mb geopotential height composite (Fig. 12) depicts a deep trough progressing eastward across the central U.S. Examination of the individual cases (not shown) show a variety of scenarios, with tornadoes occurring from a few hundred kilometers in advance of a deep longwave trough to just ahead of progressive, low amplitude shortwaves.

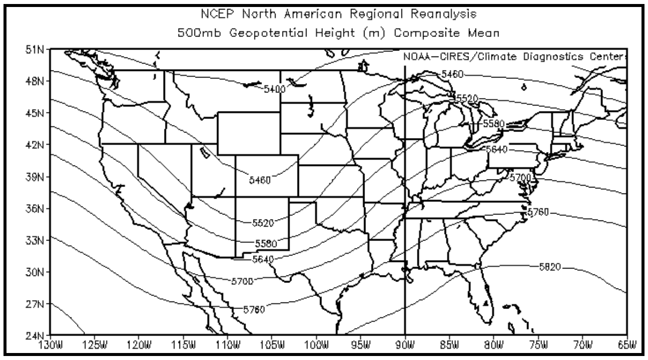


a

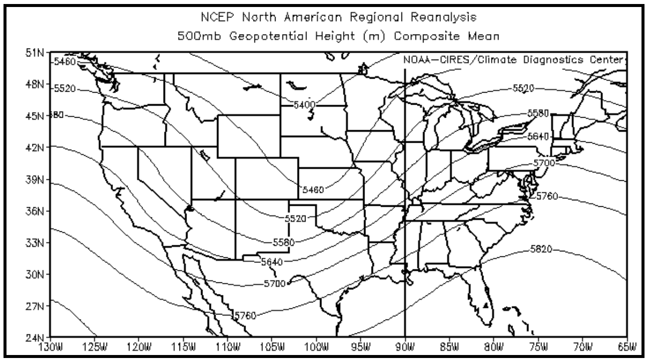


b.

Fig. 11. 300 mb Zonal Wind Composite (in m/s) for approximately (a.) 12 hours before tornado occurrence and (b.) near tornado occurrence.



a.

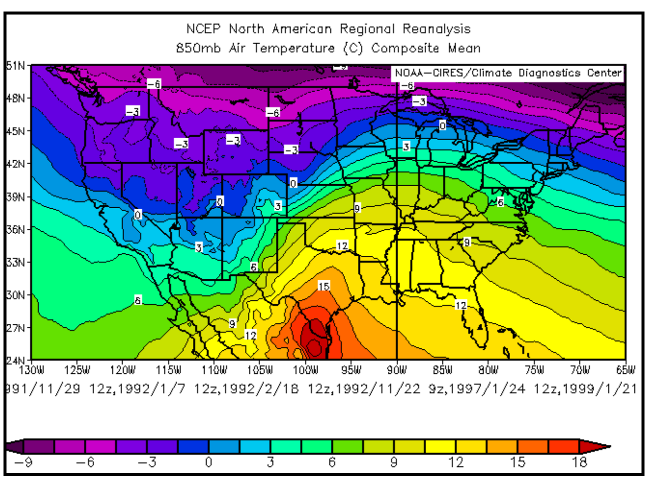


b.

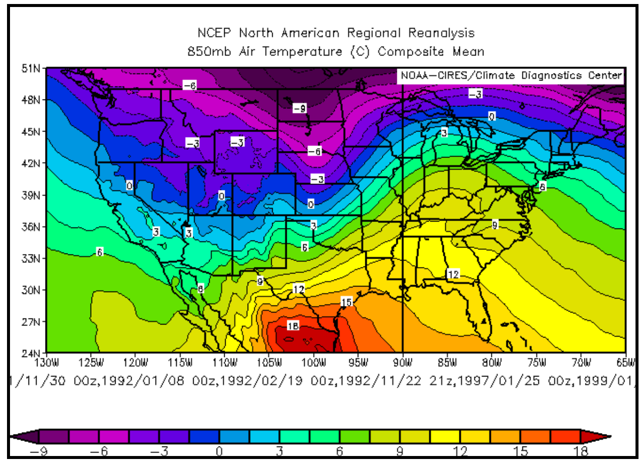
Fig 12. Same as Fig. 11., except for 500 mb geopotential heights (in meters).

A low level wind maximum is evident, with the 850mb meridional wind maximum (not shown) slightly increasing in speed (from 13 to 14 m/s), and translating northeastward across the middle Mississippi and lower Ohio River valleys. This low level jet serves to transport warm and humid air from the Gulf of Mexico seen in Figs. 13 and 14. Also of interest is the tight temperature and specific humidity gradient from the northern Great Plains southeastward which is indicative of a sharp baroclinic boundary typical of the cool season cold fronts.

Forcing of the coupled jet structure, the deep mid level trough, and the low level warm thermal advection result in greater large scale ascent over the tornado location (not shown).

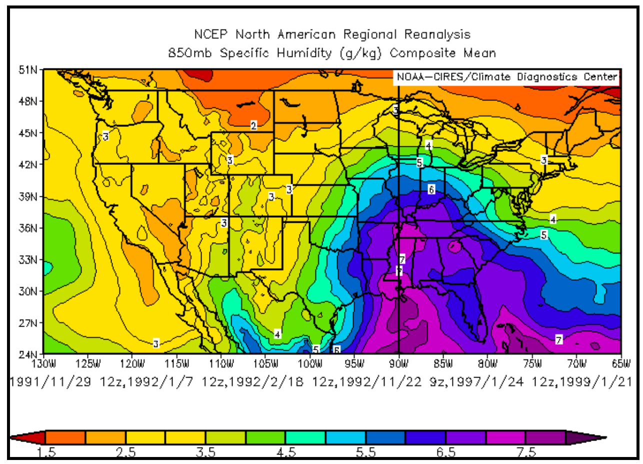


a.

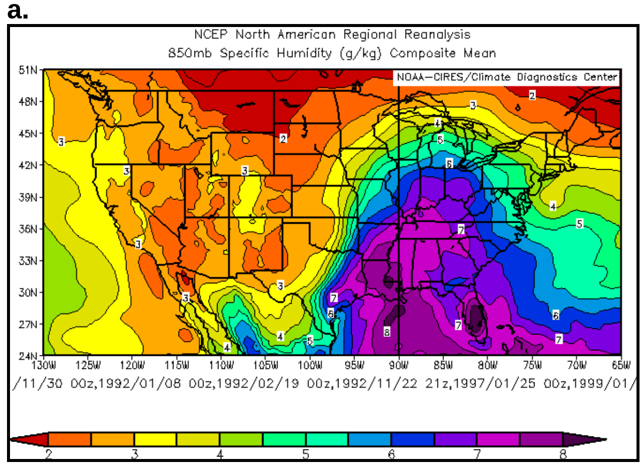


b.

Fig 13. Same as Fig. 11., except for 850 mb temperatures (in °C).



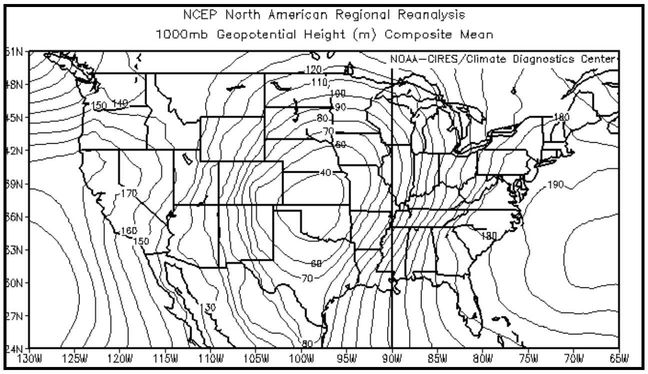
a.



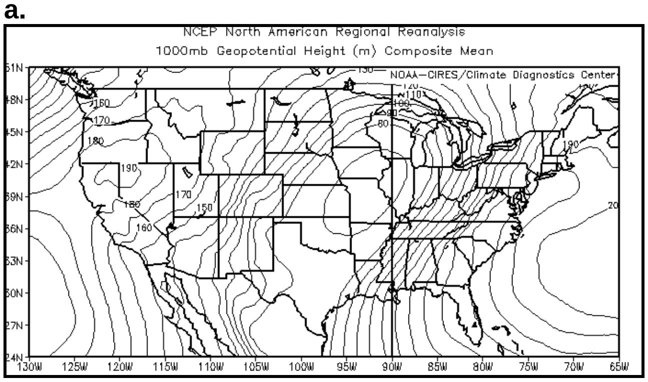
b.

Fig 14. Same as Fig. 11., except for 850 mb specific humidity (in g/kg).

The 1000mb geopotential height field (the lowest available in the NARR dataset) which is used a proxy for mean sea level pressure depicts a center of low heights moving northeastward from the central plains toward the Great Lakes (Fig 15). This path generally resembles the track of the 18 individual low tracks. The 1000mb composites do show some weakening of the low with time, but this may be the result of averaging of 18 different storms. Individual cases showed deepening, filling, and low centers maintaining their pressure the twelve hours preceding tornado occurrence.



a.



b.

Fig 15. Same as Fig. 11., except for 1000mb geopotential height (in meters).

5. CONCLUSIONS

Strong and violent tornadoes can occur at any time during the winter months, including during the late evening and overnight hours. The environments that support these storms show minimal amounts of instability with high values of shear compared to those that occur in warm or transitional seasons. Comparisons suggest that parameters using the most unstable parcel also should be examined in addition to mean parcel when evaluating near storm environments. Lower values of some of the instability parameters in this dataset may reflect the limitations of the NARR.

The higher values of bulk shear and SRH are the result of stronger wind fields experienced throughout the winter months. It is postulated that greater shear increases the likelihood of the supercell convective mode, and that vertical pressure gradient forces induced by the associated mesocyclones augment the relatively weak thermodynamic environments.

Synoptic comparisons suggest all cases occur in strongly dynamic patterns with nearby upper level jet streaks associated with progressive shortwave troughs. It is also believed that strong dynamic forcing partially offsets the lower instability. Each case also possessed a sharply baroclinic, low-level boundary moving into anomalously high moisture rich air transported northward on a low level jet.

6. ACKNOWLEDGEMENTS: The authors would like to thank Matt Bunkers for supplying a method to extract the needed environmental parameters for each sounding. They also thank Doug Tilly and Eric Lenning for their help with obtaining and analyzing the sounding data.

7. REFERENCES

Britt, M.F., and F.H. Glass, 2000: The Tornado Climatology of the St. Louis Weather Forecast Office County Warning Area. *20th Conf. on Severe Local Storms,* Orlando, FL. 88-91.

_______, and _______, 2005: Environmental Conditions Associated with Cool Season Strong and Violent Tornadoes in Missouri and Illinois. *National Weather Association 30th Annual Meeting,* St. Louis, MO. Poster Session.

Bunkers, M. J., B. A. Klimowski, J. W. Zeitler, R. L. Thompson, and M. L. Weisman, 2000: Predicting supercell motion using a new hodograph technique. *Wea. Forecasting*, **15**, 61-79.

Craven, J. P., and H. E. Brooks, 2004: Baseline climatology of sounding derived parameters associated with deep, moist convection. *Nat. Wea. Digest*, **28**,13-24.

Hart, J. A., J. Whistler, R. Lindsay, and M. Kay,, 1999: NSHARP, version 3.10. Storm Prediction Center, National Centers for Environmental Prediction, Norman, OK, 33 pp.

_________, and W. D. Korotky, 1992: The SHARP Workstation v1.50....A Skew-t/hodograph analysis and research program for the IBM and compatible PCs. NWS Eastern Region Computer Problems #13MC, National Weather Service, Eastern Region Headquarters, Bohemia, NY, 58 pp.

Mesinger, Fedor, DiMego, Geoff, Kalnay, Eugenia, Mitchell, Kenneth, Shafran, Perry C., Ebisuzaki, Wesley, JoviĆ, Dušan, Woollen, Jack, Rogers, Eric, Berbery, Ernesto H., Ek, Michael B., Fan, Yun, Grumbine, Robert, Higgins, Wayne, Li, Hong, Lin, Ying, Manikin, Geoff, Parrish, David, Shi, Wei, 2006: North American Regional Reanalysis *Bulletin of the American Meteorological Society*, **87**, 343-360

Thompson, R. L, Edwards, R., J. A. Hart, K. L. Elmore, and P. Markowski, 2003: Close proximity soundings within supercell environments obtained from the Rapid Update Cycle. *Wea. Forecasting*, **18**, 1243-1261.

Weisman, M.L. and J. B. Klemp, 1982: The dependence of numerically simulated convective storms on wind shear and buoyancy. *Mon. Wea. Rev.,* **110**, 504-520.