P8.15 SIMULATIONS OF THE SUPERCELL OUTBREAK OF 18 MARCH 1925

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1. INTRODUCTION

On 18 March 1925, the "Tri-State Tornado" left a path of nearly complete destruction across portions of Missouri, Illinois, and Indiana and killed almost 700 people - the deadliest tornado in U.S. history (Changnon and Semonin 1966). The Weather Research and Forecasting Model (WRF) is being used to conduct storm-scale simulations of this event in an effort to understand the environmental conditions and environmental changes that led to the long-track tornadic supercell thunderstorm and overall severe weather outbreak (Fig. 1).

2. EVENT OVERVIEW

The Tri-State Tornado was first reported shortly after 1 PM CST north of Ellington, MO (Fig. 2). Around 2 PM, the town of Biehle, MO was struck before the storm crossed the Mississippi River and destroyed the town of Gorham, IL a half hour later. Four other towns in southern Illinois were hit by the tornado within the hour. By 3 PM, the storm had crossed into Indiana, continuing to destroy towns and farms in its path before finally lifting around 3:30 PM (Changnon and Semonin 1966).

Maddox et al. (2011) have carefully plotted and analyzed hourly synoptic maps and found that the Tri-State Tornado and other storms that day were spawned from a low pressure system that moved out of the lee of the Colorado Rockies and into northeastern Oklahoma by 13 UTC (Fig. 3). The low pressure system brought rain to areas of Missouri and Illinois overnight and into the morning hours of the 18th (hatched region of Fig. 3), before the severe storms of interest occurred, creating a pool of cooler air that slowed the northward progression of the warm front (Maddox et al. 2011). The supercell that spawned the Tri-State Tornado appeared to form close the triple point and followed the warm frontal baroclinic zone for the majority of its track (Maddox et al. 2011).

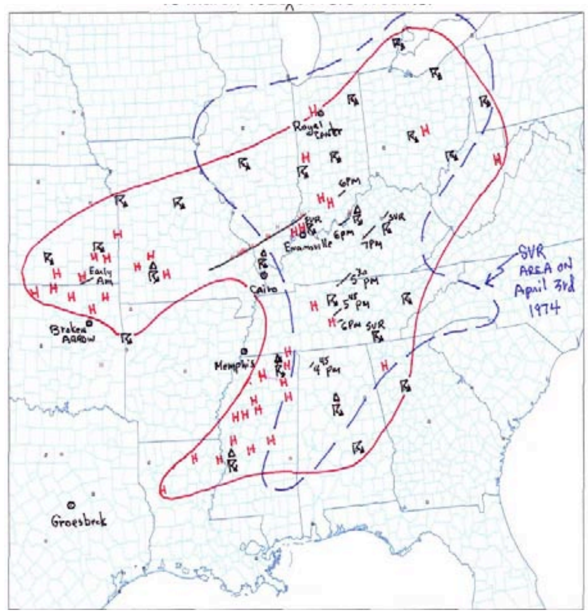

Fig. 1. Summary of severe weather reports from 18 March 1925 (from Maddox et al. 2011) within the outbreak region (outlined in red). Several tornadoes (tracks shown), thunderstorms ("˄" symbols), and widespread hail ("H" symbols) were reported. The area encompassing the 3-4 April 1974 outbreak is also overlaid for reference (purple dashed).

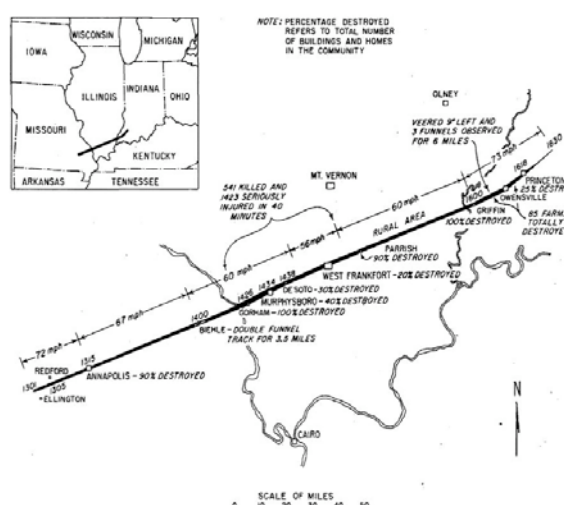

Fig. 2. The reported Tri-State Tornado 219 mi damage path (as analyzed by Changnon and Semonin 1966).

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3. METHODOLOGY

3.1. WRF Model Initial Conditions

The WRF simulations were initialized with 3-D atmospheric conditions from the 20th Century Reanalysis Project. Using only surface pressure as input, the reanalysis uses NCEP's operational global Climate Forecast System model to create an ensemble of possible 3-D atmospheric states (Compo et al. 2006, 2009; Whitaker et al. 2004): particularly useful in years predating rawinsonde observations such as 1925. The version of the NCEP ensemble model output used herein was that which resulted in 56 separate ensemble members with 2.5° horizontal resolution and 25 vertical levels.

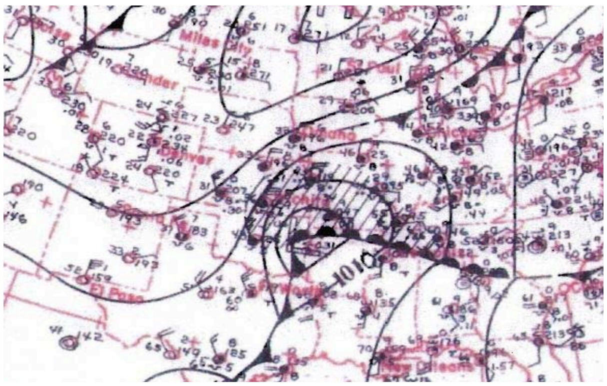

Fig. 3. Overview of the synoptic pattern at 13 UTC on 18 March 1925 as reanalyzed by the US Weather Bureau. Note the large area of rain (hatched area) north of the warm front.

Sea level pressure observations over the Tri-State region[1], many of which were not originally used as input to the climate model, were objectively compared to sea level pressure of each ensemble member from the climate model using the Model Evaluation Tools (MET) software package from NCAR's Developmental Testbed Center (DTC). This enabled choosing the ensemble member with the best 3-D state. Three of the 56 ensemble members with the highest correlations at three separate times (0, 12, and 18 UTC) are shown (Fig. 4).

Member B was chosen out of these three for the WRF simulation because not only was the correlation stronger at 12 and 18 UTC, closer to the time of the severe weather outbreak, but it also had the overall best correlation values. Furthermore, 18 UTC is a time where the climate model did not assimilated the detailed sea level pressures over the Tri-State area. Thus, that time should be the best independent check of an ensemble member's performance. Member B performed best at 18 UTC.

[1] Observational surface data was digitized from handwritten U.S. Weather Bureau forms that indicate standard station observations, but with dewpoint only recorded three times a day (01 and 13 UTC and local noon).

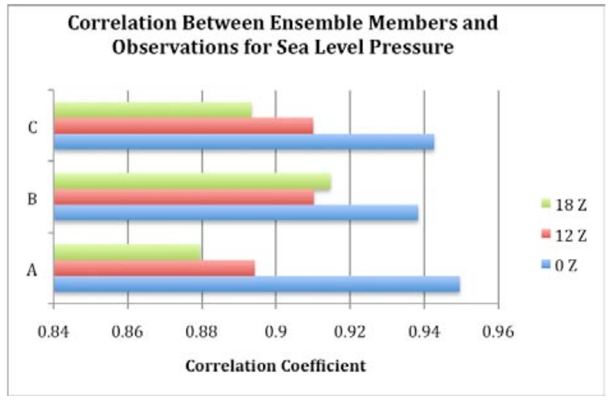

Fig. 4. Correlation results of top three members.

3.2. WRF Model Grid and Physics

Simulations were performed on NCSA's Intel 64 Cluster (Abe) with version 3.2 of the WRF model. Nests 1, 2 and 3 were initialized at 00 UTC 18 March 1925 with reanalysis data from Member B. Nests 4 and 5 were initialized at 12 UTC 18 March 1925 (Fig. 5). WRF also uses reanalysis data at 18 UTC 18 March 1925 but only as boundary conditions on the outer nest.

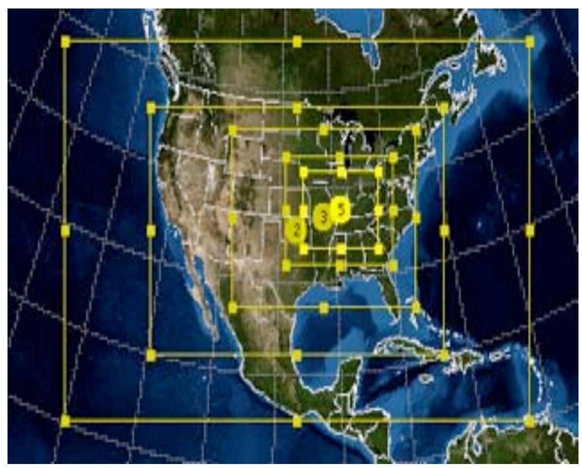

Fig. 5. The five nests used in the WRF runs.

These nests, physics packages (Table 1), and the model parameters are similar to that of Shafer et al. (2009). The outermost nest, nest one, has a dimension of 50X30 and has grid point spacing of 162 km. Nest two, which covers most of the United States and part of Mexico and the Caribbean, has 54 km grid spacing and dimensions of 94X58. The third nest focuses on the Midwest, the Southeast, and East Coast with dimensions of 178X124 and a grid spacing of 18 km. Nest four (used to create Figs. 6 and 7) has dimensions of 304X202 and 6 km grid spacing. The innermost nest, nest five, concentrates on the Tri-State area with 2 km grid spacing and dimensions of 637X466.

Table 1. Physics selections within version 3.2 WRF model

Physics	Selection
Microphysics	WDM-6 (2 moment)
Planetary Boundary Layer	YSU
Surface Layer	Noah land-surface
Convective	Kain-Fritsch
Radiation	Dudhia (shortwave), rrtm (longwave)

4.RESULTS

Comparisons between the subjective analysis and WRF model output at 13 and 18 UTC show similarities in the location of the low although the model low weakens between those two times and has more elongation in shape (Fig. 6). The surface temperature and dewpoint temperature contours are similar between the observations and WRF simulation except that the dewpoint temperatures are too cool at 13 UTC (Fig. 6). The dewpoint in WRF, however, seems to recover by 18 UTC in the Tri-State area.

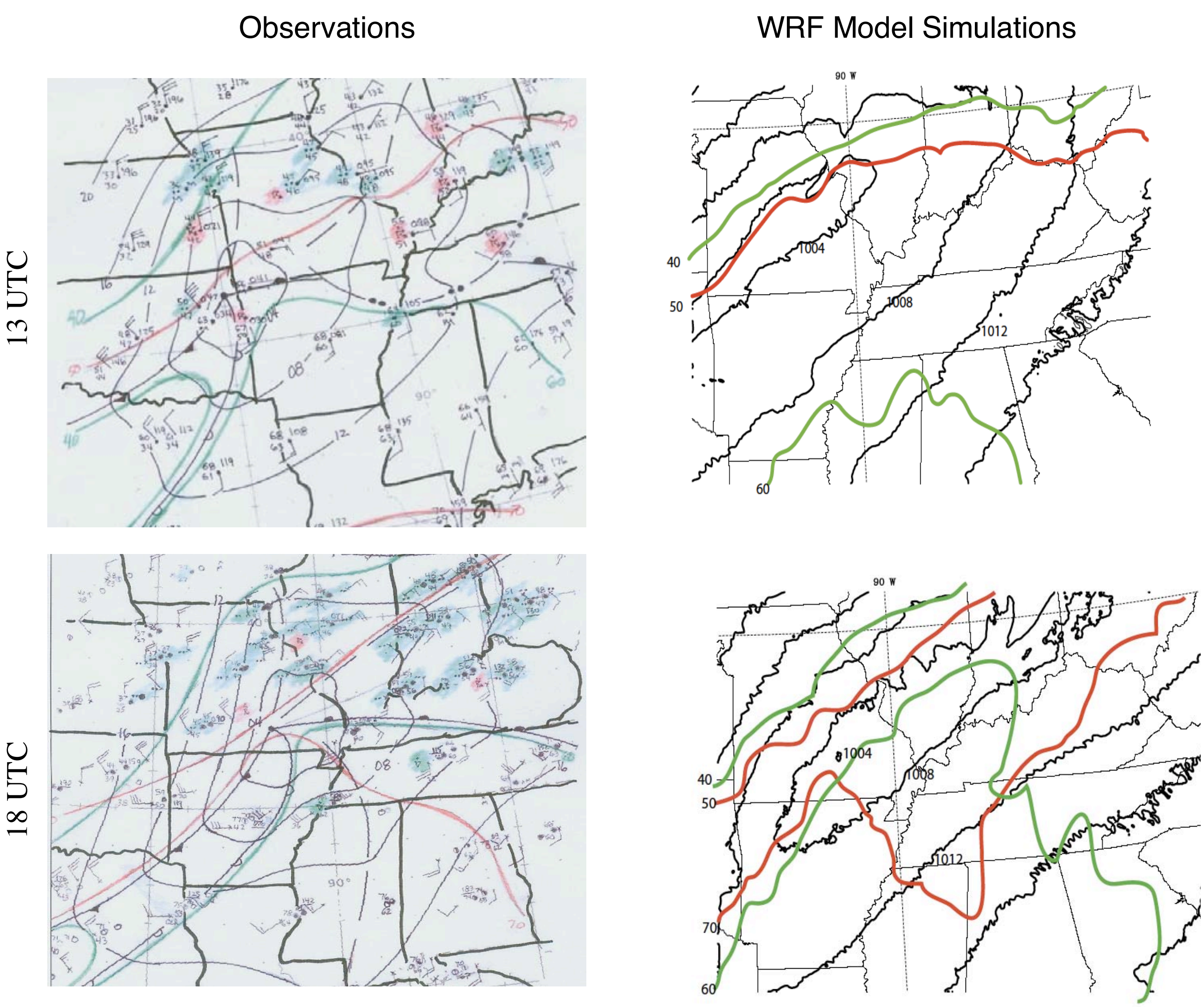

Fig. 6. Comparison of subjective analysis (left panels) and WRF model output (right panels) for 13 UTC (top) and 18 UTC (bottom). Contoured in black is pressure (every 4 hPa), in red is temperature (50 and 70°F shown only), and in green is dewpoint (40 and 60°F shown only).

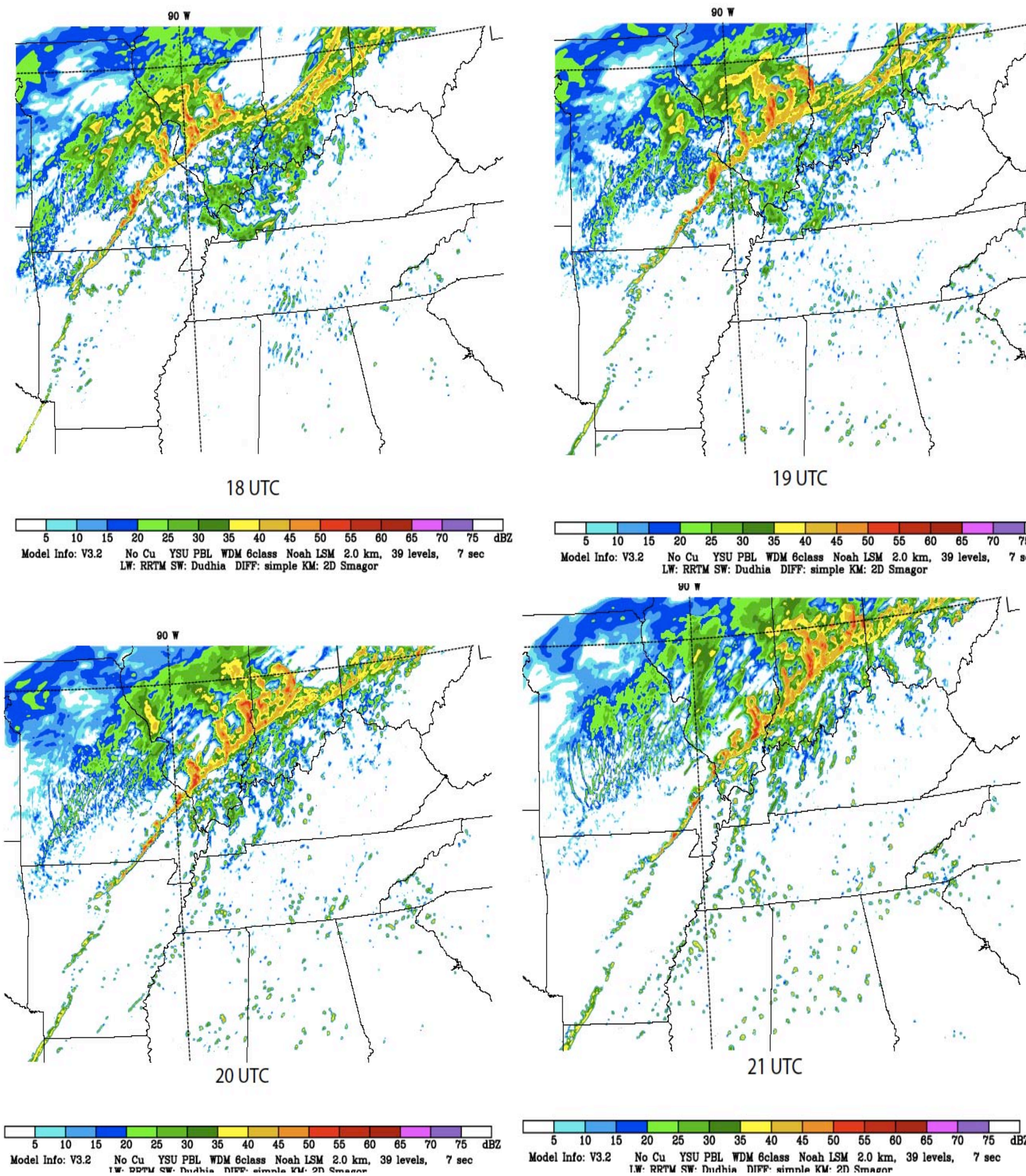

Fig.7. Sequence of simulated radar reflectivity images from 18 UTC to 21 UTC on nest #5 (2 km horizontal gridspacing).

Another difference shown in Fig. 6 is that the outflow boundary/warm front that was distinct from the separate pressure trough to the NE of the low is not distinct in the model simulation. More investigation is needed to see whether the overnight rainfall was pronounced to the NE of the low.

Remarkably, there is a dominant cell in the line that originates South Central Missouri between 17 and 18 UTC (visible in simulated radar reflectivity at 18 UTC - Fig 7a). The cell crosses the border from Missouri into Illinois at about 19:30 UTC (between Fig 7b and 7c) which is about one hour prior to that of the actual Tri-State supercell. Then the simulated dominant storm crosses into Indiana at about 21:15 (just after Fig. 7d), about 45 minutes early, but at the same location as the actual Tri-State supercell. Thus, even though the simulated dominant storm occurs too early, its motion and path is strikingly similar to the actual Tri-State supercell. Also, although the dominant storm seems to take on bow-echo characteristics in these plots, more work is needed to investigate its rotational properties.

Also, it should be mentioned that some cells in later reflectivity images in the warm sector take on a kidney-bean shape reminiscent of supercells (not shown) near where some of the other tornadic supercells occurred on this day (Fig. 1). More work is needed to investigate the cell behavior in those cases with re-simulations at finer horizontal grid spacing.

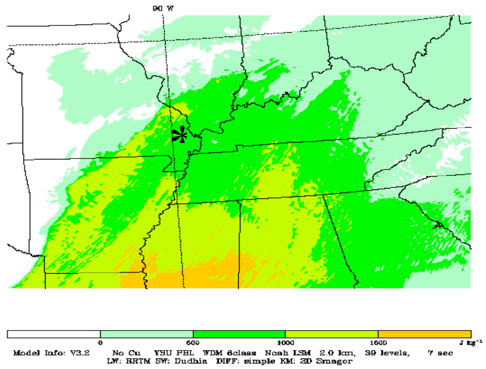

Fig. 8 Most unstable Convective Available Potential Energy (CAPE) at 18 UTC with warmer colors corresponding to larger values (see key). The asterisk denotes the approximate location of Baker, MO.

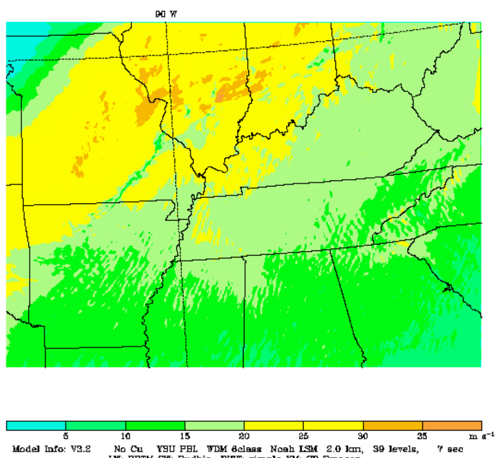

Fig. 9. Vertical wind shear from 0 to 6 km at 18 UTC with warmer colors corresponding to larger values (see key).

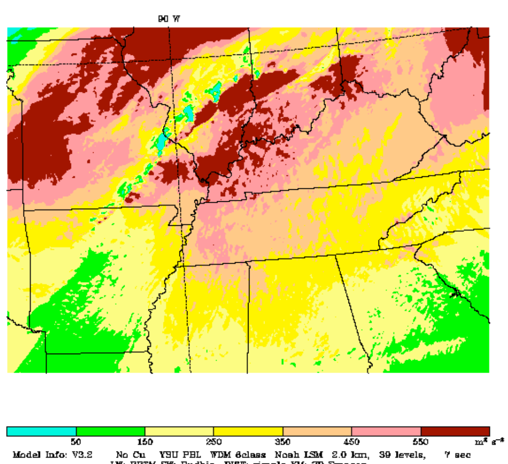

Fig. 10. Storm-relative helicity (0-3 km) at 18 UTC with warmer colors corresponding to larger values (see key).

What were the environmental parameters supporting these simulated storms? Interestingly, the CAPE values are quite small in the vicinity of the low pressure system (500 to 1000 J kg^{-1} or less in Fig. 8) - consistent with cool-season supercells (Johns et. al. 1993). Since the dewpoint temperature and temperature fields are in good agreement (simulation versus observations – Fig. 6) at 18 UTC, and since the boundary layer moisture is quite deep (Fig. 11), perhaps the Tri-State Tornado outbreak was indeed similar to other cool-season tornado outbreaks. However, it is also possible that CAPE might be erroneously small due to warm midlevel temperatures (500-300 hPA) in the reanalysis.

The vertical wind shear values at 18 UTC are largest along the baroclinic zone (Fig. 9), as expected, and are consistent with that which would support supercells (over 25 m/s of shear in the lowest 6 km). The 0-3 km SRH values within most of the warm sector are greater than 250 m^2 s^{-2} (Fig. 10): the mean value associated with F4 tornadoes (Kerr and Darkow 1996). Extreme values of 0-3 km SRH > 500 are found immediately along the warm front. (The small values of 0-6 km wind shear and 0-3 km SRH along the warm front in Figs. 9-10 are associated with regions where storms have perturbed the environmental winds.)

5. SUMMARY AND FUTURE WORK

The Tri-State tornado of 1925 remains the deadliest tornado in U.S. history. To better understand the atmospheric conditions that were in place to support this long-lived tornado, the WRF model was initialized with reanalyses from the Climate Forecast Systems Model. After choosing the ensemble member with output best correlated to actual sea level pressure observations and running WRF, the output of sea level pressure, temperature, and dewpoint temperature were compared to subjective analysis. A simulated dominant cell moved in a similar direction and speed as the Tri-State supercell. The output of CAPE, shear, and helicity suggest that the tornadic supercell may have formed in an area of high shear and low CAPE, consistent with cool-season events.

Future work will incorporate independent temperature and dewpoint readings in addition to sea level pressure when choosing the best ensemble member, testing sensitivity to different parameterization schemes, and tornado-resolving supercell simulations. Also, higher resolution reanalyses may be used as WRF input.

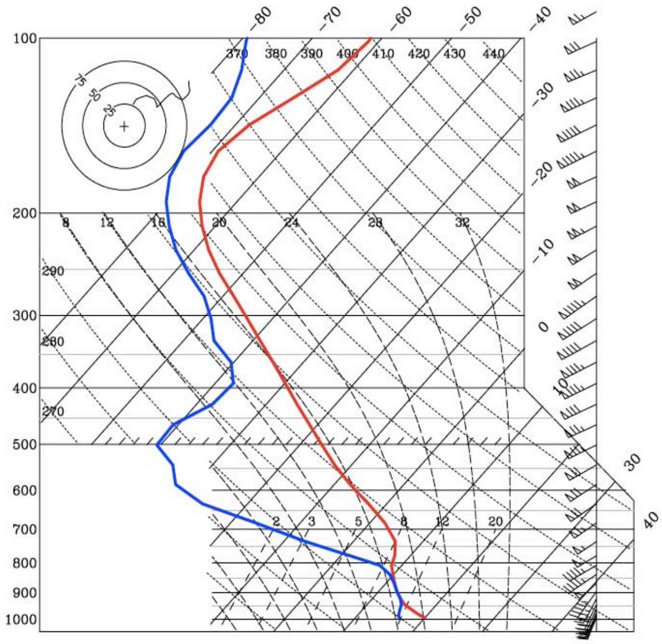

Fig. 11. Sounding from Baker, MO, 19 UTC. The most unstable CAPE on this sounding is approximately 700 J kg^{-1}. See Fig. 8 for the approximate location of Baker,MO.

6. ACKNOWLEDGEMENTS

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