11.9 A MULTI-PLATFORM APPROACH TO FORECASTING SUPERCELL TORNADO POTENTIAL

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1. INTRODUCTION

On the evening of 22 April 2004, several supercell thunderstorms formed near a stationary surface boundary located from central Oklahoma eastward along the Missouri-Arkansas border. Two supercells, in particular, moved eastward across the southern part of the County Warning Area (CWA) (Fig. 1) of the National Weather Service Forecast Office in Springfield, Missouri (KSGF), and exhibited signs of deep, persistent rotation. Numerical model output and observational data showed that the environment within the warm sector along and south of the surface

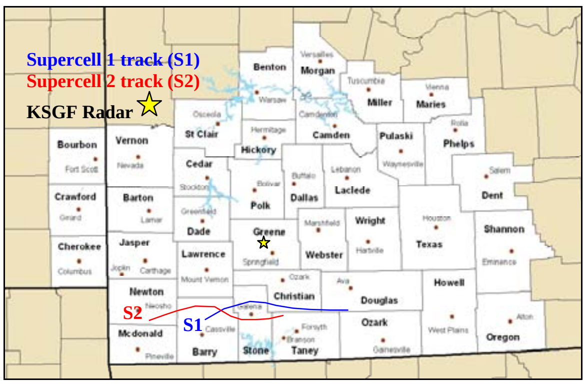

Fig. 1. Plot of the tracks of two long-lived supercells over the CWA of KSGF on 22-23 April 2004.

boundary was supportive for the formation of tornadoes. The two supercells did indeed show tornadic characteristics as indicated by WSR-88D radar, where bounded weak echo regions (BWERs), rear-flank downdrafts (RFDs), hook echoes, and deep, persistent mesocyclones were evident with both supercells. Many trained spotters reported funnel clouds and wall clouds, and nine tornado warnings were subsequently issued; however, no tornadoes were spotted, resulting in a False Alarm Ratio (FAR) of 1.0.

Reducing the FAR for tornado warnings issued by the National Weather Service is absolutely a top priority, considering that the FAR over the last 20 years has roughly hovered between 75 and 80 percent. Meanwhile, the Probability of Detection (POD) for tornado warnings issued by the National Weather Service 20 years ago was below 30 percent, but has increased to roughly 80 percent over the past five years (NWS Verification--unpublished). However, the difficulty of reducing the FAR while simultaneously increasing the POD was recently addressed by Brooks. "Increasing POD while decreasing FAR at the same time requires improvements in scientific knowledge or technological application of that knowledge, or improvements in identifying events as tornadic or non-tornadic" (Brooks 2004).

With Brooks' latter objective in mind, this paper will examine the non-tornadic supercell event over extreme southwest Missouri on 22-23 April 2004 and will illustrate the importance of using a multi-platform observational approach when forecasting tornadic potential. A brief overview of the synoptic scale and mesoscale will be discussed, followed by a detailed WSR-88D radar analysis. This will be followed by a discussion of the observational data supporting the theory that the supercells in question were likely elevated.

2. SYNOPTIC AND MESOSCALE DISCUSSION

Surface analyses from 1200 UTC 22 April 2004 indicated a surface low-pressure wave developing over southwestern Oklahoma along an inverted trough. A slowly northward-propagating warm front stretched eastward along this surface trough into central Arkansas and continued northeastward along the Ohio River Valley. The presence of another, but weaker, surface trough was also evident in the surface data. This trough stretched from the surface low into southwest Missouri (well north of the synoptic boundary), and was likely caused by early morning convection. The morning convection generated a cold pool over northeastern Arkansas and south central Missouri, and surface winds over southwest Missouri backed to the east in response.

Upper air analyses from 22 April 2004 indicated a deep longwave trough and associated closed low at 500 hPa over the Nevada-Utah border at 1200 UTC. Downstream from this feature, a shortwave trough extended southeastward into the central plains where a 25 ms^{-1} mid-level jet streak existed over central Oklahoma. As the shortwave continued moving downstream during the day, the longwave trough moved southeast, and was positioned over the four corners region by late afternoon. Winds at 500 hPa consequently backed ahead of this strengthening trough, and increased as the 28 ms^{-1} mid-level jet now extended into southwestern Missouri.

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By late afternoon, the surface low-pressure wave was located over central Missouri, and the synoptic warm front had surged northward into northern Arkansas. Surface temperatures were in the middle 70s and lower 80s in the warm sector, while dewpoint temperatures ranged from the middle 60s to lower 70s. Both surface temperatures and dewpoints were about 10 degrees cooler north of the synoptic boundary. This strong baroclinic discontinuity resulted in a large instability gradient by 0000 UTC 23 April, as the 100 hPa mixed-layer CAPE north of the surface boundary was 900 Jkg^{-1}, and 3000 Jkg^{-1} south of the surface boundary.

Although the majority of the instability was located in the warm sector, the strongest wind shear was located north of the boundary. The 0000 UTC 23 April 2004 sounding from SGF indicated over 30 ms^{-1} of deep layer shear (0-6 km), which is considered favorable for supercells. Surface winds were easterly and northeasterly at about 5 ms^{-1}, and increased and veered with height (up to 6 km and above). This created a very favorable shear environment for tornadic supercells, as evidenced by the 0-1 km helicity value of 284 m^2s^{-2}, and the 0-3 km helicity value of 475 m^2s^{-2} (not shown). Because of the favorable environment for tornadic supercells, the NWS Storm Prediction Center issued a tornado watch and emphasized that isolated tornadoes were possible near any surface boundaries.

3. RADAR DISCUSSION

Although strong to severe elevated convection affected central Missouri—within the KSGF CWA—as early as 1700 UTC 22 April 2004, the radar discussion will focus solely on the supercells that formed later over extreme southwestern Missouri. Radar data from the WSR-88D in Springfield, Missouri (KSGF) will be used.

As the low-pressure wave approached, showers and thunderstorms developed by 2100 UTC over extreme southwest Missouri in the general vicinity of the surface warm front. The first signs of supercellular convection were observed over northern Barry county (labeled S1 in Fig. 1) just before 2300 UTC 22 April 2004.

Concurrently, another supercell formed further to the west over southern Newton county (labeled S2 in Fig. 1). Two other supercells formed upstream of this storm at roughly the same time (along with other multi-cell convection), making a total of four supercells (Fig. 2). Although the two western-most storms were long-lived and showed some tornadic characteristics, they were not as strong or persistent as S1 and S2.

As stated before, S1 and S2 showed signs of being tornadic by about 2300 UTC 22 April 2004. Recent research (Markowski et al. 2002) has shown

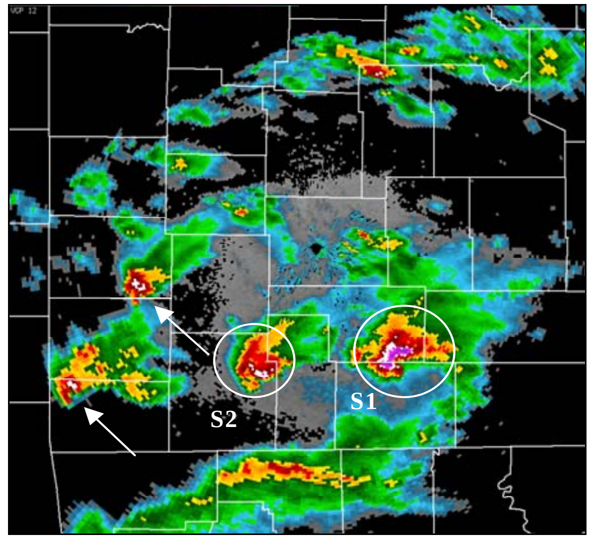

Fig. 2. KSGF 0.5 degree base reflectivity valid at 0100 UTC 23 April 2004. The two main supercells S1 and S2 (encircled in white), and two other, less intense supercells (indicated by arrows) are identified.

that tornadogenesis involves the presence of three key ingredients: (1) a persistent, rotating updraft (i.e., a spatially and temporally consistent mesocyclone), (2) enhanced storm-relative helicity (i.e., backed low-level winds with veering and increased speeds with height), and (3) a relatively warm RFD (i.e., low dewpoint depressions within the near-storm environment). All of these necessary conditions seemed to be present on the evening of 22 April 2004. Both S1 and S2 displayed deep and persistent rotation, as the mesocyclone associated with S1 (S2) lasted for nearly three (two) hours. Backed winds, especially north of the warm front, enhanced low-level storm relative helicity (Fig. 3). Furthermore, surface observations and RUC40 analyses indicated dewpoint depressions of roughly 10^{o}F or less, from which low lifting condensation level (LCL) heights and thus ample low-level buoyancy can be inferred (not shown).

As the supercell thunderstorms strengthened in this environment, radar data indicated that S1 and S2 demonstrated features that often occur prior to tornadogenesis. Characteristics such as BWERs, RFDs, hook echoes, and persistent mesocyclones were all witnessed during the event. Figure 4, for example, illustrates a reflectivity cross-section of S1 retaining a BWER, which indicates an intense updraft. The collapse of this updraft (which later did occur, but is not shown) often precedes tornadogenesis (Lemon and Doswell 1979).

At the same time, the storm-relative velocity of S1 showed deep, strong rotation, which was confirmed by two tornado vortex signature (TVS) detections (not shown). The TVS is a WSR-88D radar algorithm that is often a sign of an incipient or embryonic tornado

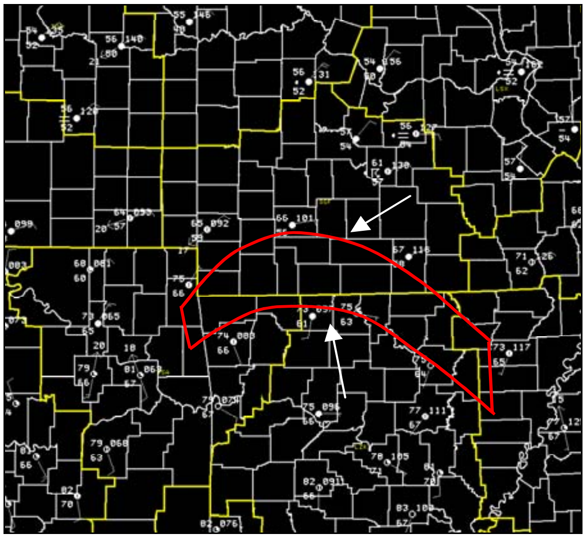

Fig. 3. Surface observation stations valid at 2300 UTC 22 April 2004. Based on these surface data, the warm front is positioned somewhere within the red, outlined area, with the appropriate wind directions north and south of the boundary (bold, white arrows).

and sometimes precedes tornadogenesis. Twenty-seven of these were identified during this event.

Referring back to Fig. 3, S1 and S2 formed and propagated eastward near the front. However, with the lack of a reflectivity fine line and high-resolution mesonet observational data, the exact position of the warm front relative to S1 and S2 was difficult to ascertain. Thus, the lack of fixed observation stations in extreme southern Missouri made it impossible to determine if the supercells were elevated or surface-based.

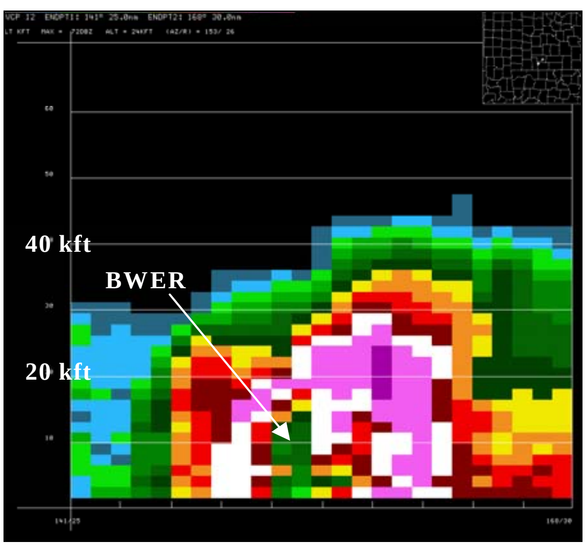

Fig. 4. Reflectivity vertical profile for S1 valid at 0039 UTC 23 April 2004. The white arrow identifies the bounded weak echo region (BWER).

Given the favorable environment within the warm sector, and number of tornadic characteristics these supercells exhibited, the tornado warnings that were issued seemed justified. Yet, none of the tornado warnings verified, creating a FAR of 1.0 and a POD of 0.0. In order to improve tornado warning accuracy, it is necessary to determine differences between tornadic and non-tornadic supercells. One way to achieve this goal is to integrate multiple sources of real-time observational data into the analysis of the near-storm environment (NSE).

4. MULTI-LEVEL ANALYSIS OF THE NSE

Although S1 and S2 appeared tornadic per the KSGF WSR-88D radar, further investigation showed that the supercells were likely slightly elevated, situated just north of the warm front. As already discussed, observational surface data were not able to resolve the exact location of the front, though the data did show it was positioned somewhere within a 100-km swath south of Springfield, Missouri (Fig. 3).

The vertical wind profiler at Conway, Missouri (50 km northeast of Springfield and just north of the 100-km swath), showed low-level winds that were generally east-southeasterly from the surface to over 2 km at 1300 UTC 22 April 2004, which is indicative of the stable boundary layer (Fig. 5). Throughout the day; however, these boundary layer winds veered from the top of this stable layer, and by 0100 UTC 23 April 2004, the stable boundary layer had thinned to a depth of about 1 km. This demonstrates that the warm front (and corresponding warm air advection above the boundary layer) was mixing northward during the day. Although the warm front did not reach Conway, it can be inferred that it was relatively close.

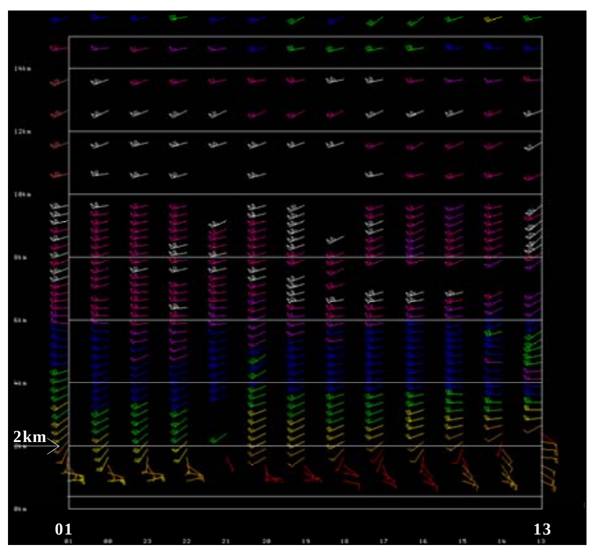

Fig. 5. Wind profiler data from Conway, MO, valid from 1300 UTC 22 April – 0100 UTC 23 April (from right to left). Low-level easterly winds thinned over the 12-hour period. The 2-km level is highlighted.

Despite the important wind profiler data, it still was not clear how far northward the warm front had moved throughout the day. Thus, it was necessary to take a look at the situation not from the surface, but aloft, and from an observing platform that can record movement. Consequently, visible satellite imagery was used in a post-analysis to help locate the position of the warm front.

To this end, the visible satellite image valid at 2215 UTC 22 April 2004 proved to be extremely useful (Fig. 6). Billow clouds existed over southwest and south central Missouri, indicating the presence of stable low-level air (Scofield and Purdam 1986; Weaver et al. 1994). Therefore, the surface warm front was likely located as little as 15 km south of the track of the supercells. As a result, the satellite imagery supports the theory that the supercells were slightly elevated, leading to a decreased chance for tornadoes because the RFD was unable to penetrate the cool, stable boundary layer (Markowski et al. 1998).

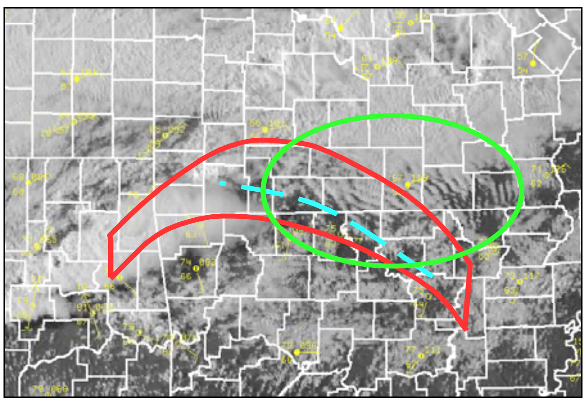

Fig. 6. Visible satellite image valid at 2215 UTC 22 April 2004. The red-dashed box refers to the approximate position of the warm front (from Fig. 3). Billow clouds can be seen over south central Missouri indicative of the low-level stable layer (encircled in dashed green line). The location of the warm front can then be inferred from these clouds (blue dashed line).

5. SUMMARY

This paper detailed the evolution of the 22-23 April 2004 severe weather event across extreme southwest Missouri. A total of nine tornado warnings were issued for two long-lived supercells displaying tornadic characteristics; however, none of the warnings verified. The unknown location of the warm front was crucial because it was difficult to determine if these supercells developed within an environment supportive of the formation of tornadoes.

The use of a multi-dimensional analysis was necessary to find the exact location of the warm front and its position relative to the supercells. Surface observations and profiler data were found to be too coarse to locate the warm frontal position. However, satellite imagery proved most useful in this case because the stable boundary layer was identified via the presence of billow clouds. The billow clouds formed north of the warm front in the stable air. The supercells tracked only about 15 km north of the warm front when looking at the relative position of the billow clouds on satellite. Thus, the supercells were elevated, and would likely not have produced tornadoes.

Therefore, satellite imagery could have limited the number of tornado warnings that were issued after the initial warnings did not verify, which could have lowered the resulting FAR. However, it is the use of all supplementary data that is needed to lower the FAR and simultaneously raise the POD in an event where coarse data are inadequate.

6. REFERENCES

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