AN ANALYSIS OF THE JUNE 23RD, 2002, BROWN COUNTY, SOUTH DAKOTA TORNADIC CYCLICAL SUPERCELL

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1. INTRODUCTION

On 23 June 2002, a supercell thunderstorm that moved through McPherson and Brown Counties, South Dakota, spawned at least six tornadoes during its life cycle (Fig. 1), one of which caused the first documented occurrence of F4 tornado damage in Brown County. Post analysis of the radar data shows that the parent thunderstorm was a cyclic supercell and its long life cycle and repetitive tornado production was related to its interaction with several synoptic and subsynoptic scale boundaries. The purpose of this paper is to present a brief examination of the synoptic and thermodynamic controls of this event and to show how the interaction of the storm with various boundaries contributed to a shear environment favorable for repeated tornado production.
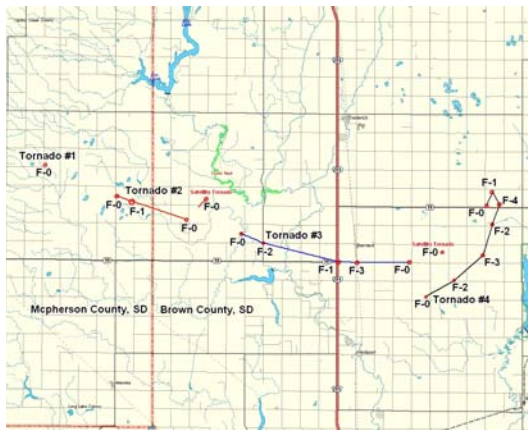

Figure 1 – Tracks of the six documented tornadoes and their relative Fujita Scale Rankings (courtesy of NWS Aberdeen).

2. SYNOPTIC AND THERMODYNAMIC CONTROLS ON INITIATION AND SUPERCELL GENESIS

2.1. *Synoptic Scale Environment*

The synoptic-scale environment associated with the initiation of the Brown County event is summarized by Fig. 2. A marked trough of low pressure in the middle and upper troposphere dominated the region. This trough was associated with substantial synoptic-scale upward motion in the middle troposphere over the upper Midwest. Pressure falls ahead of the trough were associated with the development of a complex surface low pressure system with two distinct centers (Fig 3).
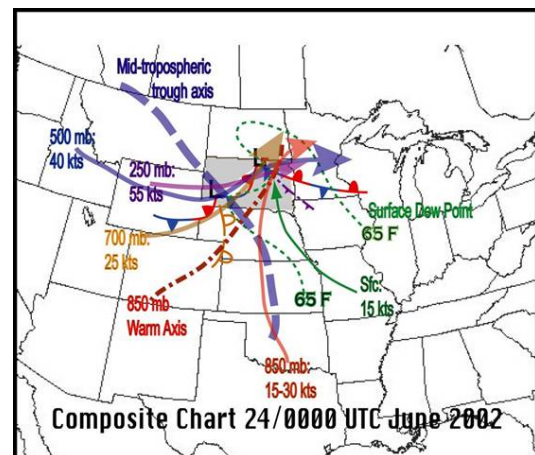

Figure 2 - Composite chart of synoptic and subsynoptic features as explained in the text.

The western-most low-pressure center was related to a wave along the front and encouraged the development of a dry line bulge into west central South Dakota. The eastern-most center was associated with another wave, but was interacting with an outflow boundary moving westward from pre-existing convection in eastern South Dakota and western Minnesota. Warm advection (not shown) characterized the lowest 200mb of the atmosphere from the eastern quarter of South Dakota into the eastern half of South Dakota.

Above 850mb, west-southwest winds had brought a warm, dry layer over the underlying very moist air mass at the surface. The resulting cap was very strong south of Aberdeen, but weakened enough (due to the arrival of a 250mb jet streak) north of the axis of warmest 850mb temperatures. The arrival of the jet streak also helped strengthen the deep layer shear and assisted with the explosive development of the Brown County supercell.
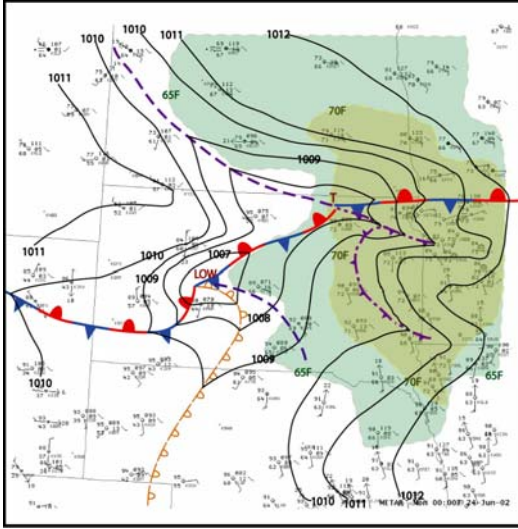
Figure 3 – Subsynoptic analysis, 0000 UTC, 24 June 2002. "T" indicates the approximate position of the updraft area of the Brown County supercell at the time of the analysis. Boundaries shown are those evident in the synoptic scale data and do not include additional boundaries found on the basis of the radar evidence.

2.2. *Thermodynamic and Shear Environment*

The synoptic features described in the previous section contributed to explosive instability over north-central South Dakota, with surface based Convective Available Potential Energy (sbCAPE) of around 4000 J/kg at 0000 UTC (Table 1 and Fig. 4). The lack of Convective Inhibition (CIN) in the sounding just north of the 850mb warm axis allowed initiation within this area, but not further south. Additionally, deep layer shear (e.g., 0-6 km) was very large and was within the favorable range for storms to become supercellular (Weisman and Klemp, 1986).

Table 1 : Parameters calculated on the basis of the 0000 UTC KABR sounding shown in Fig. 4.

sbCAPE	4010 J/kg
0-6 km Shear	25.9×10^{-3} s^{-1}
0-3 km Storm Relative Helicity*	159 m^2 s^{-2}
*Initial Storm Motion	270/12kts
0-1 km Shear	5.8×10^{-3} s^{-1}
BRN Shear	30 m^2 s^{-2}

It is important to note that low level shear values were rather weak and not consistent with values observed with tornadic storms elsewhere (see Johns and Doswell, 1992 and Monteverdi et al. 2003). In short, the synoptic scale environment was characterized by buoyancy and shear favorable for supercells, but not for tornadic supercells.
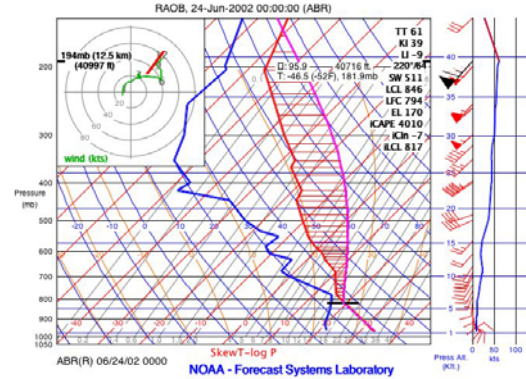

Figure 4 - KABR sounding, 0000 UTC 24 June 2002. Red hatched area indicates sbCAPE for surface lifted parcel.

As the Brown County supercell moved southeastward, the inflow air was no longer drawn from the region south of KABR but from the region east and north of the outflow boundary moving west from eastern South Dakota. A proximity sounding constructed from the KABR 0000 UTC sounding with surface temperature and dew point from the region just north and east of the outflow boundary (in the area east of KABR) was analyzed (not shown). This sounding showed more sbCAPE (~4500 J/kg vs. ~4000 J/kg) and surface winds more backed (80° vs. 110°) producing nearly double the amount of 0-1 km shear (10.5 x 10^3 s^{-1}).

Not only was the storm intercepting the solenoidally-generated vorticity associated with the boundary, it had also moved into a region characterized by significantly greater sbCAPE and low level shear. These factors can partially explain why the storm became more deviate and became a cyclic tornado producer. Such interactions were similar to those observed by Markowski et al. (1998) and Rasmussen et al. (2000) for the Texas Panhandle supercells that became tornadic when crossing into a more favorable environment on the cool side of an outflow boundary.

3. RADAR AND SATELLITE IMAGERY

One of the most important aspects of the Brown County supercell was the evolution of the storm and its interactions with several boundaries (Fig. 5). The subsynoptic analysis illustrated in Fig. 3 shows only two of the boundaries due to insufficient coverage of surface observations. However, the radar imagery shows additional pronounced boundaries interacting with the storm at various times and in complex ways.

Initial development of the storm occurred in McPherson County, north of the synoptic-scale front. Around 0000 UTC, a complicated set of synoptic boundaries were propagating across northeastern South Dakota [labeled (1), (2), (3) and (4), on Fig. 5]. Initial storm motion was dictated by the environmental hodograph (Fig. 4), which suggested movement slightly south of east. The resulting southeastward motion of the storm, from McPherson County into

Brown County, lead to its interaction with the synoptic scale boundary and boundary (2) surging westward from earlier convection in western Minnesota and Iowa. At the time of the first tornado (~00:20 UTC), the intersection of this outflow boundary and synoptic scale front was apparently collocated with the updraft area of the storm (not shown).
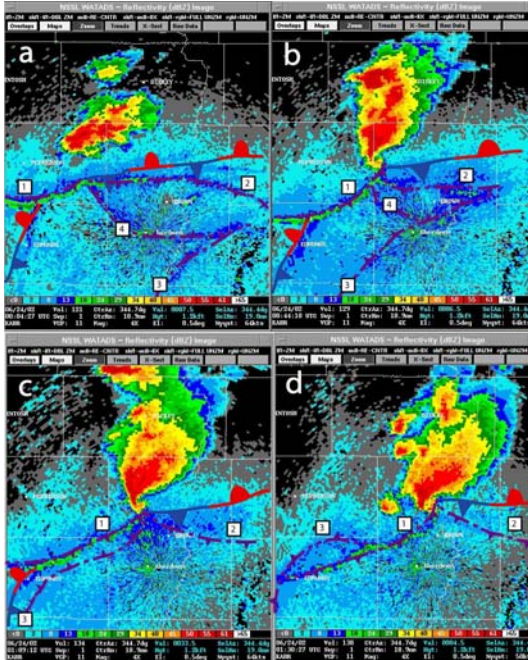

Figure 5 – KABR WSR-88D reflectivity plots for 00:04:27, 00:44:18, 01:09:12 and 01:30:27 UTC. Outflow boundaries indicated by numbers (1), (2), (3) and (4) (as discussed in Section 3). F4 tornado occurred about the time of the lower right hand panel. (Imagery generated using WSR-88D Algorithm Testing and Display System).

As discussed in Section 2, we believe that this first interaction significantly increased the low level shear and made the storm-scale environmental hodograph more favorable for supercell tornadogenesis and stronger deviate motion. Markowski et al. (1998) and Rasmussen et al. (2000) hypothesized that the updraft of storms interacting with previously existing outflow boundaries tilts and stretches the horizontal vorticity upward shortly before tornadoes occur. In the case of the Brown County supercell, the evidence suggests a similar set of circumstances. The motion of the storm would have had the effect of tilting solenoidally-generated horizontal cyclonic vorticity on the outflow boundary into the updraft in much the same manner.

Two additional boundaries [labeled (3) and (4) on Figs. 5a] played a very important role in the evolution of the storm. The northern edge of boundary (3) and most of boundary (4) were ingested into the storm updraft around 0100 UTC (Fig. 5b and 5c). We believe that it is no coincidence that the strongest tornado (associated with the F4 tornado) occurred shortly after these interactions (Fig. 5d). Figure 6 shows the intense rotation signature (couplet)

seen from the velocity field using a storm relative motion of 100° at 10m/s from the KABR WSR-88D radar at the approximate time of the F4 tornado.
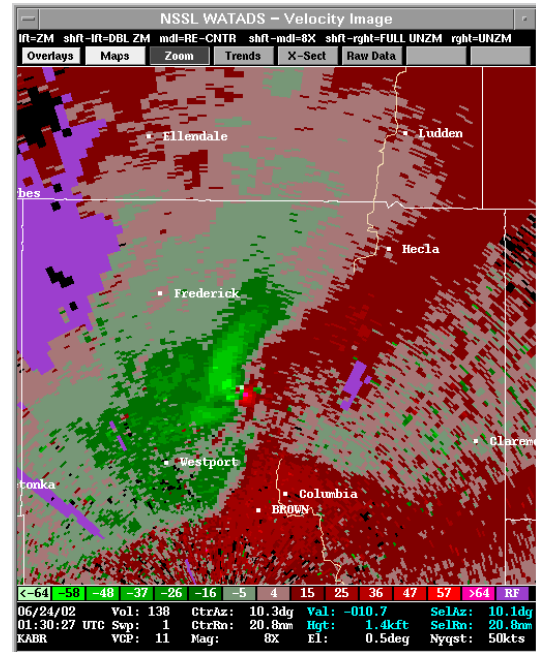

Figure 6 – Velocity image at 01:30:27 UTC using storm relative motion parameters showing the mesocyclonic couplet of the storm's updraft at approximately the time of the F4 tornado. (Imagery generated using WSR-88D Algorithm Testing and Display System).

At the time of the F4 tornado (~0130 UTC), visible satellite imagery (Fig. 7) shows that the anvil had spread out in a near circular fashion and a vigorous overshoot can be seen near the center of the anvil. Other cells that were briefly tornadic can be seen near Bismarck, ND. The storm that developed near Pierre, SD was associated with the western-most low pressure center but was never tornadic.

4. SUMMARY

In review, we believe that the radar data demonstrates that the storm became a supercell when the storm motion dictated by the synoptically generated shear profile (hodograph) brought it close enough to the synoptic scale boundary (1) and outflow boundary (2) to ingest the baroclinically generated vorticity and high CAPE. The low-level shear profile (and modified hodograph) made the storm move substantially to the right and kept it on boundary (2) for an extended period (Fig. 5). Boundary (3) was likely the biggest contributor to producing the F4 tornado (Figs. 5d, 6 and 8) as it added its effects along with boundaries (1), (2) and (4) in the storm's final stages as a supercell.

The behavior of the Brown County storm as it intercepted the many boundaries present in eastern South Dakota on 23 June 2002 was consistent with that observed by Markowski et al. (1998) and

Rasmussen et al. (2000). For those supercells present in the Texas panhandle, only the storms that became
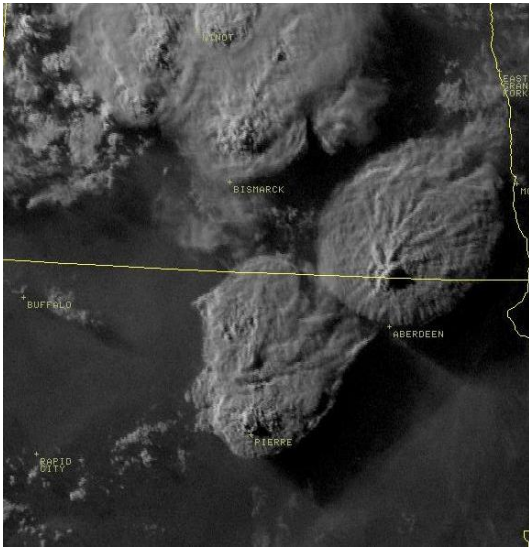

Figure 7 – Visible Satellite image at 0130 UTC, the approximate time of the F4 tornado.

tornadic were those that crossed or interacted with previously existing outflow boundaries. Multiple boundary interactions with the Brown County storm contributed to its long life and to its cyclical nature. When the storm interacted with two boundaries early in its life cycle, it produced tornadoes ranging from F0 to F3 (Fig. 1). However, the most significant tornado, an F4, was produced when all four boundaries intersected beneath the updraft during the latter stages of the storm's life. Sufficient deep layer shear, moisture and helicity were in place to support supercell storms over the region on the afternoon of 23 June 2002. The boundary interactions subsequent to storm initiation clearly played a large role in helping the storm maintain severe and tornadic characteristics over a sustained period.

Figure 8 – The tornado that produced F4 damage in Brown County.

5. REFERENCES

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