13.6 DOPPLER RADAR OBSERVATIONS OF SQUALL LINE TORNADOGENESIS NEAR THE KDVN WSR-88D

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1. INTRODUCTION

On 14 June 2001, a squall line developed in northern Missouri in a moderate shear, high instability environment. The squall line moved rapidly into eastern Iowa, bowed, then produced two tornadoes in addition to widespread wind damage. One of the tornadoes caused F2 damage and the other F1 (NOAA 2001), and both occurred within 10nmi (~20km) of the KDVN WSR-88D. The tornadoes developed near the bow's apex, close to the intersection of the squall line with an external boundary. The boundary developed due to differential heating and was reenforced by flash flood producing thunderstorms which occurred earlier that day.

Tornadoes associated with squall lines typically pose a great challenge for meteorologists attempting to provide warning lead time (see, e.g., Wolf 2000). Indeed, these circulations developed rapidly and in a non-descending mode (mode II) (Trapp and Davies-Jones 1997). Thus, radar sampling limitations, both temporal and spatial, are especially critical in these events relative to classic supercell thunderstorms producing tornadoes in a descending mode (mode I). Moreover in most years, squall lines seem to produce the majority of tornadoes in eastern Iowa, and perhaps other parts of the Midwest, compared to classic supercells.

The evolution of the two vortices, radar sampling issues, and the prospect for improvement with the new radar scanning strategies proposed for the WSR-88D will be discussed.

2. SYNOPTIC AND MESOSCALE BACKGROUND

At 12 UTC 14 June 2001, a vertically and meridionally deep trough extended north-south through the U.S. Rockies. An upper tropospheric jet streak was apparent east of the trough over the Central and Northern Plains rounding the top of a ridge in the upper Midwest. The 500mb trough was developing a negative tilt. The Gulf of Mexico was wide open into the Midwest with 850mb flow of 40-60kts (20-30ms^{-1}) extending from the Gulf northward to Lake Superior. A surface low was located in the Missouri River Valley near Sioux Falls, SD, but the key surface feature was a boundary located along the Mississippi River in eastern Iowa - northwest Illinois shown in Figure 1. The visible satellite imagery depicts a cloud-covered eastern Iowa with temperatures generally in the 70s, and a cloud-free area in northwest Illinois where temperatures averaged around 90°F. An 18Z sounding at Davenport, Iowa (DVN) near this boundary measured a CAPE around 4100 Jkg^{-1}, a surface-6km shear of 33kts (17 ms^{-1}), and abundant dry air in the mid troposphere (Fig. 2).

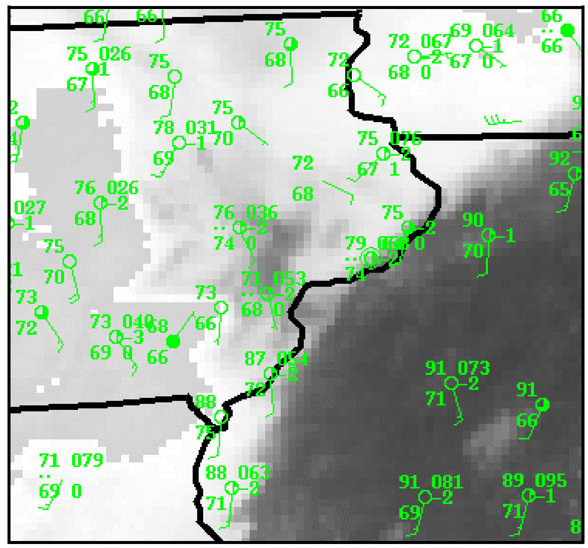

Figure 1. 21 UTC surface observations and visible satellite imagery.

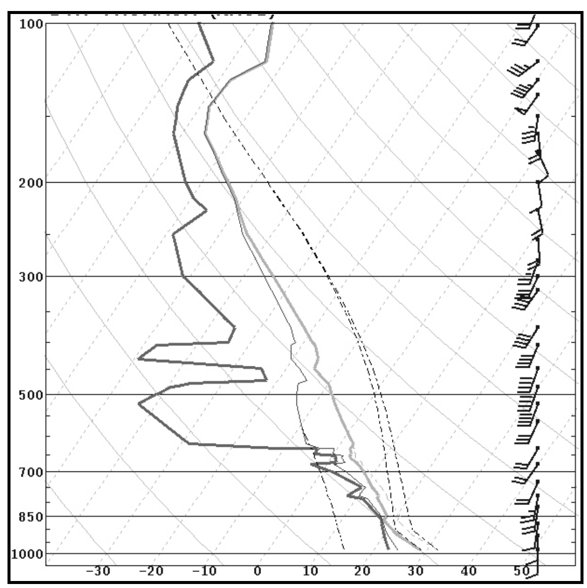

Figure 2. 18 UTC DVN observed sounding.

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3. RADAR OBSERVATIONS

3.1 Blue Grass tornado

The vortex associated with the Blue Grass tornado first appeared on radar in the storm-relative velocity imagery (SRM) at 2255 UTC. The lowest two elevation scans, sampling at 1-2kft, measured Vr shears averaging 28kts (Fig. 3). This feature was associated with an inflow notch in the 0.5° reflectivity imagery along the leading edge of the squall line. At 2300 UTC, a user-defined TVS was observed at 0.5° (Fig. 4, right) and the circulation had deepened to around 13kft. The inflow notch was still apparent in the 0.5° reflectivity image (Fig. 4, left). The vortex produced a tornado starting at 2300 UTC which caused F2 damage in the town of Blue Grass, about 10 nmi (~20km) southwest of the radar. The circulation intensified at 2311 UTC, but its depth can only be estimated in excess of 7kft because of sampling limitations resulting from the cone of silence. Despite the strength of the circulation, the greatest shears were not gate-to-gate as at 2300 UTC, and the damage survey and a trained spotter report indicated straight-line wind damage at this time. The circulation, though deep, weakened at 2316 UTC then dissipated shortly after 2321 UTC. A distinct and essentially continuous damage path was observed along the entire track of the radar-observed vortex. This particular vortex did not appear to be associated with an external boundary as observed in Schmocker et al (2000) and Crosbie and Wolf (2002).

3.2 Bettendorf tornado

At 2306 UTC, a convergent signature appeared in the 0.5° storm-relative velocity imagery, associated with a rapidly developing cell located along the leading edge of the squall line. A downburst from a nearby cell may have contributed to the strength of the convergence. At 2311 UTC, the convergent signature persisted while moderate to strong cyclonic rotation (average Vr = 38kts) developed above it to a height of at least 12kft. The cell was located at the intersection of an external boundary with the squall line, as seen in the 0.5° reflectivity imagery in figure 5 (left). A tornado, which caused F1 damage, was reported at this time (location indicated by the arrow in figure 5, right). Cyclonic rotation persisted through a depth of about 9kft in the next volume scan (2316 UTC), while rotational velocities in the lowest three elevation scans (up to around 2kft) increased. By 2321 UTC, the storm had become outflow dominated with only weak rotation apparent above 5kft. The tornado dissipated around 2320 UTC.

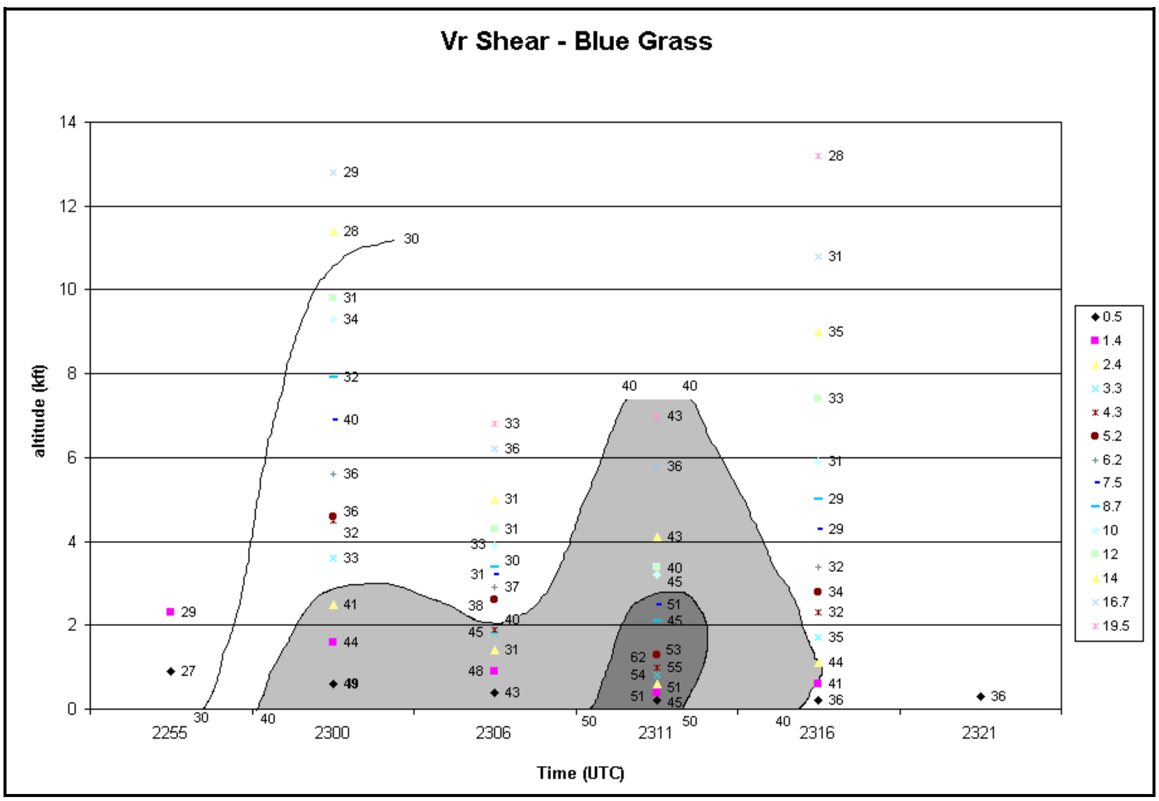

Figure 3. Rotational velocities (kts) for the Blue Grass circulation. The tornado occurred between 2300 and 2306 UTC.

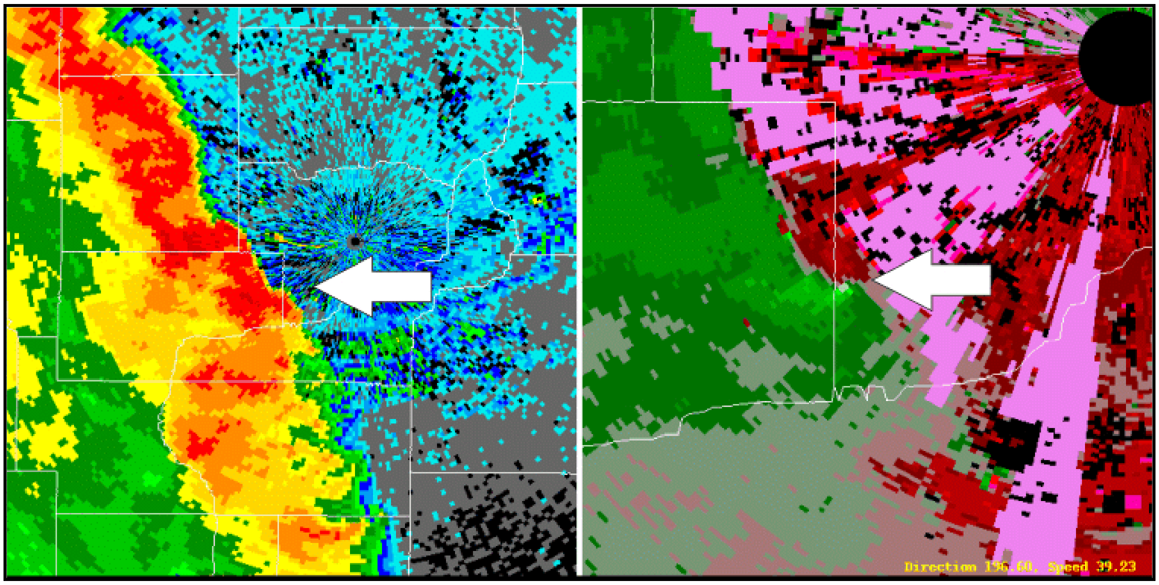

Figure 4. KDVN 0.5° reflectivity and storm relative velocity imagery (SRM) at 2300 UTC. Note the notch in the reflectivity data (arrow on left) and the intense gate-to-gate circulation in the SRM data (arrow on right).

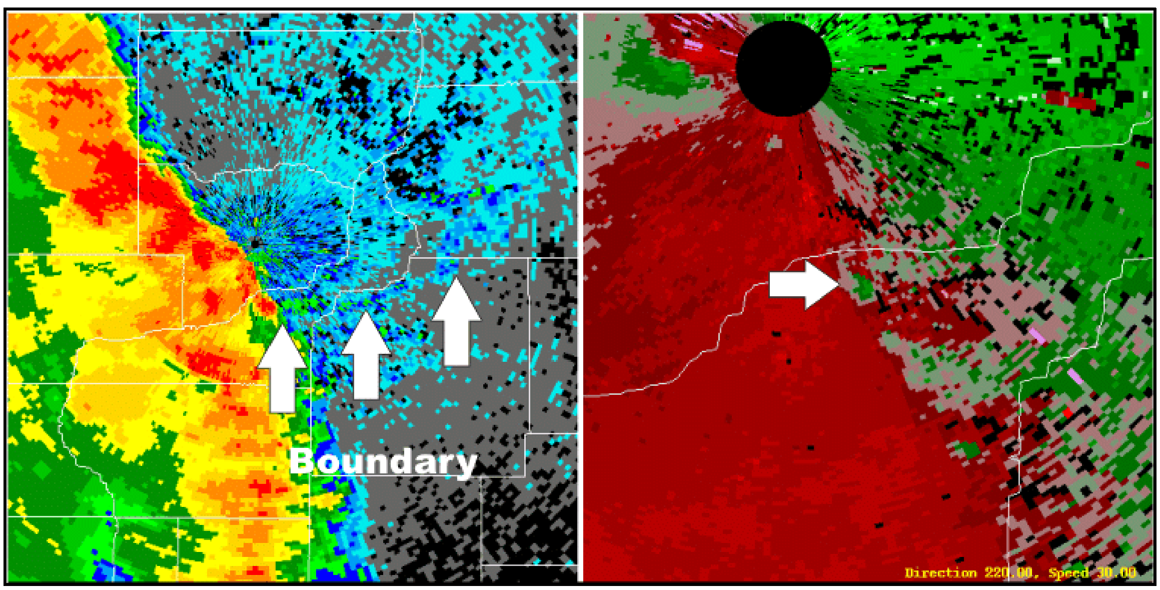

Figure 5. KDVN 0.5° reflectivity (left) and storm relative velocity imagery (right) at 2311 UTC. Note the boundary in the reflectivity imagery, and the strong convergence in the SRM image at the time and location of the F1 tornado.

4. DISCUSSION

The Blue Grass vortex developed at 2255 UTC, starting near the surface then building upward. This would not have been evident if the storm was located beyond 35nmi from the radar, because the 0.5° beam elevation would be sampling above the circulation at those distances. The volume scan at 2300 UTC provides sufficient resolution to detect the actual tornado in the vicinity of Blue Grass, only 10nmi from the radar. However, the evolution of the depth of the vortex at 2306 and 2311 UTC is not possible to resolve because the circulation extended into the cone of silence as it neared the radar site. The occurrence of the tornado was concurrent with the strongest gate-to-gate shears, but not with the strongest shears which occurred in the larger-scale vortex.

The Bettendorf vortex also developed rapidly but was shorter lived. It initially appeared as a low-level (<1kft) convergent signature at the intersection of an external boundary with the outflow boundary from the squall line, similar to the cases reported by Schmocker et al (2000) and Crosbie and Wolf (2002). This signature would not have been apparent beyond about 25nmi from the radar. The F1 tornado developed concurrently with the observation of deep cyclonic rotation in the storm-relative velocity imagery above 0.5°. At 0.5°, the convergent signature persisted until 2316 UTC. In the time of one volume scan, the storm developed from a low-level convergent signature to an 11kft deep tornadic mesocyclone. These tornadoes were similar to some of the tornadic events reported in Forbes and Wakimoto (1983).

The Bettendorf storm was moving in a different direction than the mean storm motion, so the storm-relative velocity data did not clearly indicate the circulation at 2306 UTC. The deviant motion may have been due to interactions with the external boundary. A more accurate storm motion applied in post-analysis resulted in a more obvious signature. Operationally, a vortex within a squall line moving at a deviant motion from the mean will provide an additional challenge for the warning forecaster.

New WSR-88D scanning strategies, in addition to the Multiple Pulse Repetition Frequency Dealiasing Algorithm, may prove beneficial for sampling these types of vortices (Steadham et al 2002). Faster scanning rates will help address temporal sampling issues. The increased vertical resolution and higher quality velocity data would help address vortex sampling at longer ranges, however the problem with increasing beam elevation at increasing range from the radar will remain. It is critical for National Weather Service warning operations that data made available by these improvements is quickly infused into the AWIPS datastream, and that training efforts are developed to take advantage of these new schemes combined with the latest knowledge on squall line tornadogenesis.

In summary, two cases of tornadogenesis very close to the radar and each other in both space and time were observed. The Blue Grass circulation did not appear to evolve under the influence of external factors as did the Bettendorf circulation. This presents another operational challenge since it appears squall line tornadoes develop in different ways, and that forecasters must deal with these issues not always having the benefit of storms occurring so close to the radar.

5. REFERENCES

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