3.3 UNDERSTANDING WSR-88D SIGNATURES FOR THE 3 MAY 1999 OKLAHOMA CITY TORNADO

Donald W. Burgess[1] and Michael A. Magsig[1,2]
[1]National Weather Service/Operational Support Facility, Norman, Oklahoma
[2]Cooperative Institute for Mesoscale Meteorological Studies (CIMMS)

1. INTRODUCTION

The 3 May 1999 Oklahoma City tornado was unique from a radar perspective because a long-track violent tornado passed within close range of several Doppler radars: The Twin Lakes WSR-88D (KTLX), the OSF Test WSR-88D (KCRI), the TDWR at the FAA PSF (near OKC), and two University of Oklahoma Doppler on Wheels (DOWs). The DOWs (Wurman *et al 1997)* were generally 0.5 to 4 miles from tornado, and the other radars had ranges of 7 to 20 miles to the tornado. The quality of the data set was improved by having the Norman weather community contribute large amounts of resources to a detailed survey of the damage that was conducted immediately after the event (Stumpf *et al*, 2000).

Although base data from all radars have been analyzed, complete time-height histories of signatures have been prepared only for KTLX, the central Oklahoma operational radar. The data from this radar should be most like the data from other WSR-88Ds across the country.

Having a complete time-height history of the reflectivity and velocity signatures from KTLX affords an opportunity to investigate how the radar signatures relate to tornado existence, strength, and damage. Having multiple Doppler radars at close range to a large violent tornado affords opportunity to study radar sampling issues associated with detection of tornadoes and the complex flow fields surrounding them. Better understanding of tornado reflectivity and velocity fields will lead to better operational radar application in tornado warning decision making.

2. TORNADO TRACK

The Oklahoma City tornado was the 9th in a series of 14 tornadoes produced by Supercell A of the outbreak (see Stumpf *et al*, 2000). It began near Amber at 2327 (all times are UTC). From there it traveled northeast, growing wide and intense before striking Bridge Creek about 2350 (see Fig. 1). The tornado narrowed and weakened some between 0005 and 0015 before again widening somewhat and regaining intensity as it struck southwest Oklahoma City and Moore between 0020 and 0030. The tornado remained intense, but not nearly as wide as near Bridge Creek, as it turned more northerly, striking southeast Oklahoma City, Del City and Midwest City. The tornado dissipated at 0047 after a lifetime of 80 minutes.

Corresponding author address: Donald W. Burgess, National Severe Storms Lab, 1313 Halley Circle, Norman, OK 73069 (405)366-0414
email: dburgess@nssl.noaa.gov

3. REFLECTIVITY SIGNATURES

A well-defined hook was present with the supercell (see Fig. 1 insets) that had been in existence for 1.5 hours by the time of the beginning of the Oklahoma City tornado. Throughout the tornado's life, the hook featured a prominent knob that defined the location of the circulation detected by radar. Figure 2 is a time-height depiction of the maximum reflectivity in the knob and in the echo area above where the knob identity is lost in other overhanging precipitation. Note that higher reflectivities (> 55 dBZ) in the knob begin near 2350 (the time Bridge Creek was struck), extend up to 10,000 ft, and continue until the beginning of the weakening period about 0005. The higher reflectivities in the knob begin again just after 0015, grow upward, become more extensive, and continue through the rest of the tornado's life. This is the period during which the tornado traveled almost exclusively through populated areas (the Oklahoma City metropolitan area) with high potential for large amounts of debris. The second reflectivity maxima in the knob is more reflective (>70 dBZ) and extends to higher heights (at least 20,000 ft) when compared to the first maxima. In fact the 70 dBZ values are 10 dBZ higher than reflectivities present anywhere else in the storm during the same period.

It is postulated that the localized reflectivity maximum in the knob of the hook emanates from large amounts of debris being lofted to high heights by the tornado. Tornado debris lofting to high heights has been noted previously (Magsig and Snow, 1998). This suggests that the existence of very large reflectivity in the knob of the hook can be used to infer that a tornado is present and is inflicting significant amounts of damage, perhaps structures in metropolitan areas.

4. VELOCITY SIGNATURES

The traditional tornado proxy of strong and localized velocity difference (Tornadic Vortex Signature; TVS) as depicted by gate-to-gate differences was found to be confusing for the May 3rd data. This was because of the tendency for the localized velocity maxima to be separated across several azimuths. To obtain results that compared favorably with tornado location and documented changes in tornado intensity (F-Scale rated damage), a different approach was necessary. By taking the maximum velocity difference across a distance of less than 1 n mi at low elevation angles where the radar beam height was less than 3,000 ft Above Radar Level (ARL), a good correlation between velocity difference (delta V)

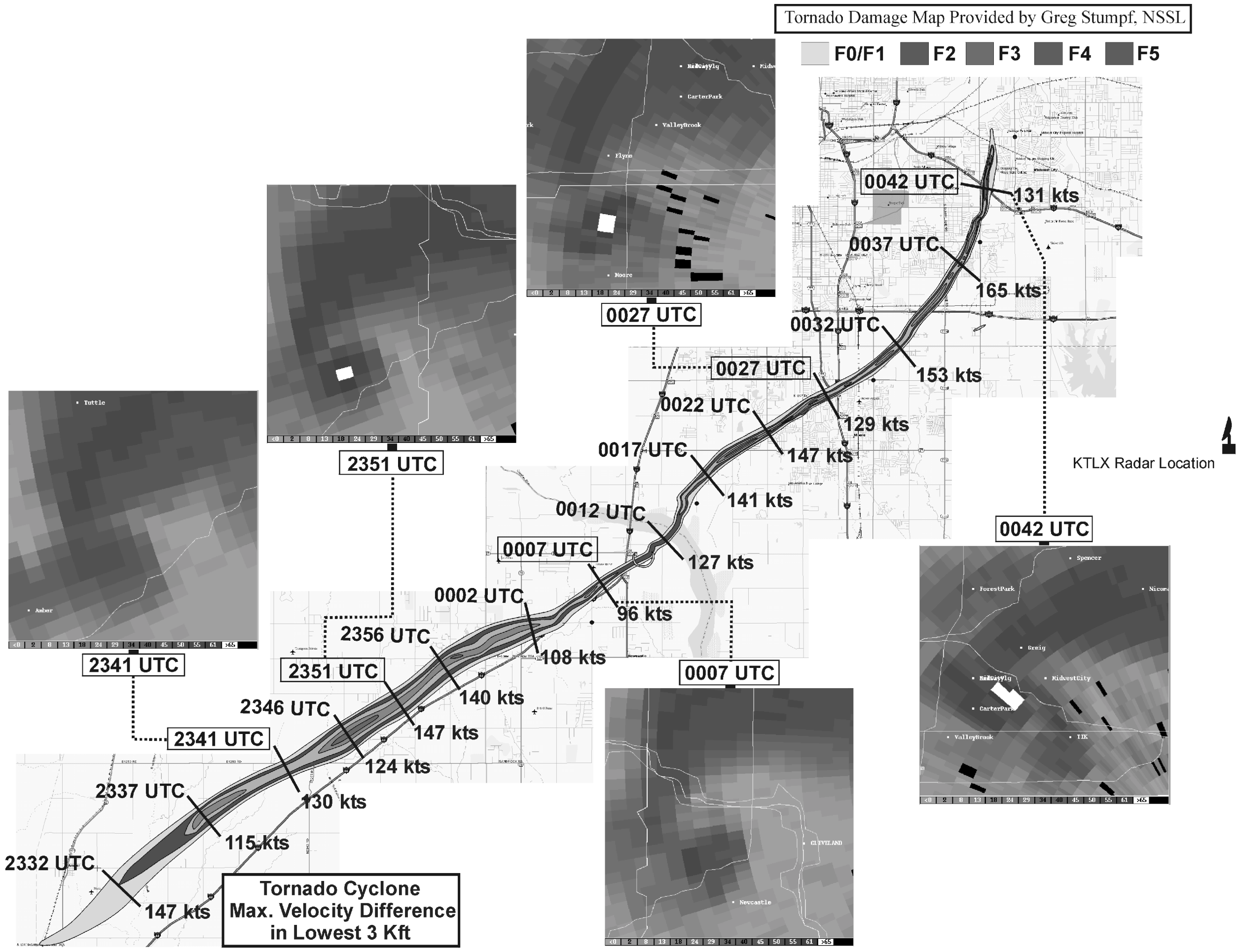

Figure 1. Tornado damage track, maximum velocity differences, and 0.5 degree reflectivity images from KTLX.

and F-Scale was found (Fig. 2). The scale size of the phenomena being measured is best described as the tornado cyclone because subsequent analysis shows the vortex detected by the ground-based radars is larger than the tornado. Delta V rapidly exceeded 120 kts as the tornado formed and stayed above that value during the time period when the tornado damage was at F5 intensity. Delta V lessened to below 100 kts as the damage intensity dropped to F2. Delta V quickly increased again and stayed at or above 130 kts during the rest of the life of the tornado as the intensity returned to F5. Delta V remained large and tornado intensity remained high until just the last two or three minutes of the tornado's life.

A time-height section of tornado cyclone Delta V (Fig. 2) reveals that values were already somewhat high before tornado formation (> 80kts), but were aloft. Very large values (>100 kts) formed through a deep column as the tornado formed (2327). A first tornado cyclone maxima quickly formed and continued until about 0000; maximum values remained at heights below 15,000 ft ARL. Strengthening occurred about 0015 and a deeper column of very large Delta V's continued until rapid weakening at tornado end. Measurement of the vertical extent of the tornado cyclone's second maxima of high Delta V values is limited by the radar "cone of silence" produced when the storm approached the radar and the highest elevation angle (19.5^0) intersected the circulation at only 20,000 ft. Note that, although the column of very large Delta V's was deep, the highest Delta-V values (>150 kts) were typically found at the lower elevation angles.

5. DISCUSSION OF VELOCITY SIGNATURES

The difficulty in relating close-range gate-to-gate WSR-88D velocity differences to the tornado is worthy of further discussion. The lack of the traditional TVS gate-to-gate relationship was present for both KTLX and KCRI. The noisy character of the TDWR data in the vicinity of the tornado prevented comparison with that radar. One of the possible reasons for the lack of a meaningful gate-to-gate signature is that, at close range, the large diameter of the tornado might produce a signature spread across several azimuths. To check this possibility and to better define the velocity field in and around the tornado, DOW data were examined. Comparison of DOW data with KTLX and KCRI data for two times (Fig. 3) indicates that

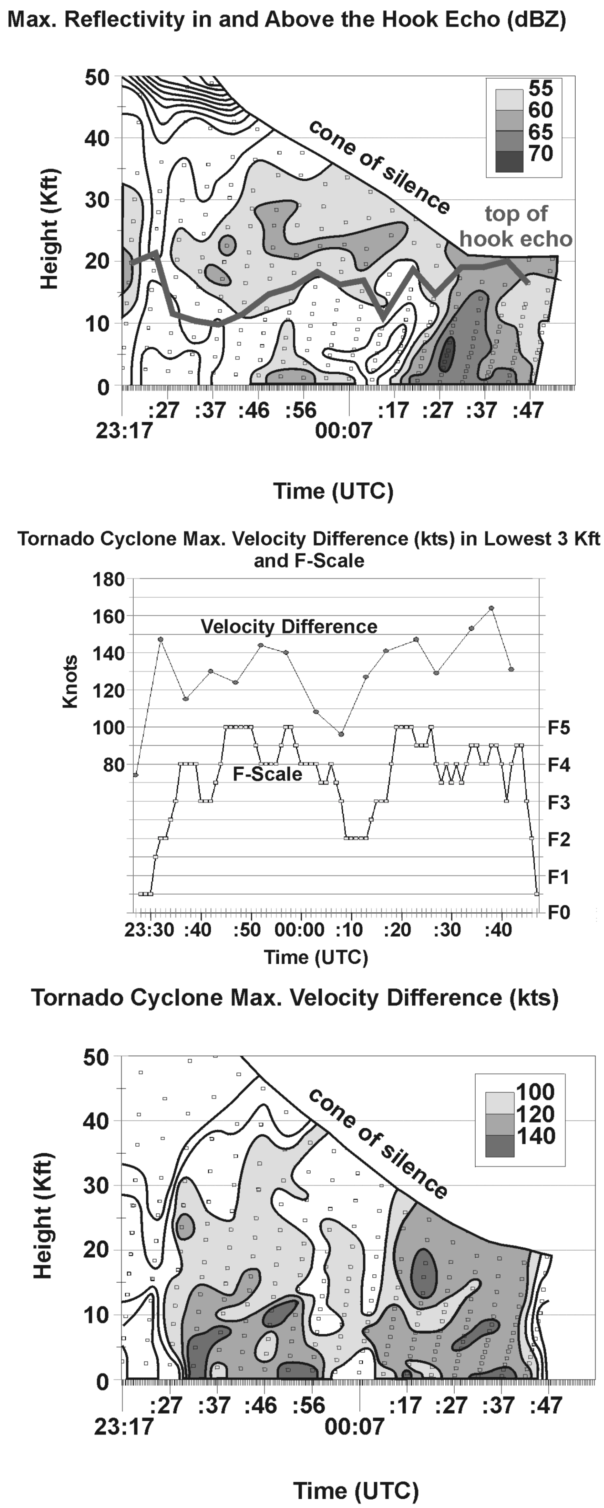

Figure 2. Reflectivity time-height (top), F-scale and velocity difference time series (middle) and velocity time-height (bottom) from the KTLX radar.

the tornado diameter is smaller than the WSR-88D Delta-V signature. This is true even when taking into account the possibility that sampling of the tornado vortex along its centerline could produce a signature spread across three azimuths instead to two. Other sampling issues exist. One is that radar returns used to measure velocity are power weighted. If the large amounts of debris present with the tornado are being centrifuged to locations outside of the radius of maximum tornado wind and are traveling at slower speeds, echo from the highest-wind area may be too weak to be properly detected. Note that the DOW data, particularly at 0013, indicate that there are is a well-defined signature (velocity peaks) larger than the tornado...the tornado cyclone. Thus, the WSR-88D returns may be more related to the tornado cyclone and less related to the tornado itself. If this is correct, tornado cyclone strength must be closely related to tornado strength to produce the good correlations between radar-detected TVSs and tornadoes.

6. CONCLUSION

Operational WSR-88D signatures in reflectivity and velocity are useful in detecting and tracking tornadoes. The May 3rd Oklahoma City tornado had a reflectivity signature that was related to debris-produced large dBZ values. Such values, when present in the knob of the hook, and when the signature is over debris-producing areas, may be used to infer the presence of a damaging tornado. The May 3rd WSR-88D velocity signatures, perhaps on a scale slightly larger than the tornado, well depicted tornado location and gave some idea of tornado strength. Note that this was true for reflectivity and velocity signatures at close range (<20 n mi). Detecting and tracking tornadoes becomes increasingly difficult as range grows longer.

The full understanding of tornado velocity signatures remains unknown. In collaboration with University of Oklahoma and NSSL scientists, the authors hope to pursue further analysis of the May 3rd dataset to better understand the meaning of the WSR-88D signatures and to enhance their utility in warning decision making .

7. ACKNOWLEDGMENTS

We gratefully acknowledge Josh Wurman (OU) and David Dowell (OU and NSSL) for the DOW data used in this paper and Greg Stumpf for the damage track.

8. REFERENCES

Magsig, M.A. and J.T. Snow, 1998: Long-distance debris transport by tornadic thunderstorms. Part 1: The 7 May 1995 supercell thunderstorm. *Mon. Wea. Rev., 126*, 1430-1449.

Stumpf, G.J., D. Speheger, and D.W. Burgess, 2000: Verification of tornado events in the Norman, Oklahoma, NWSFO county warning area for the May 3, 1999 severe weather outbreak. This volume.

Wurman, J., J.M. Straka, E.N. Rasmussen, M.Randall,and A. Zahari, 1997: Design and deployment of a portable, pencil-beam, pulsed, 3-cm Doppler radar. *J. Atmos. Sci., 14*, 1502-1512.

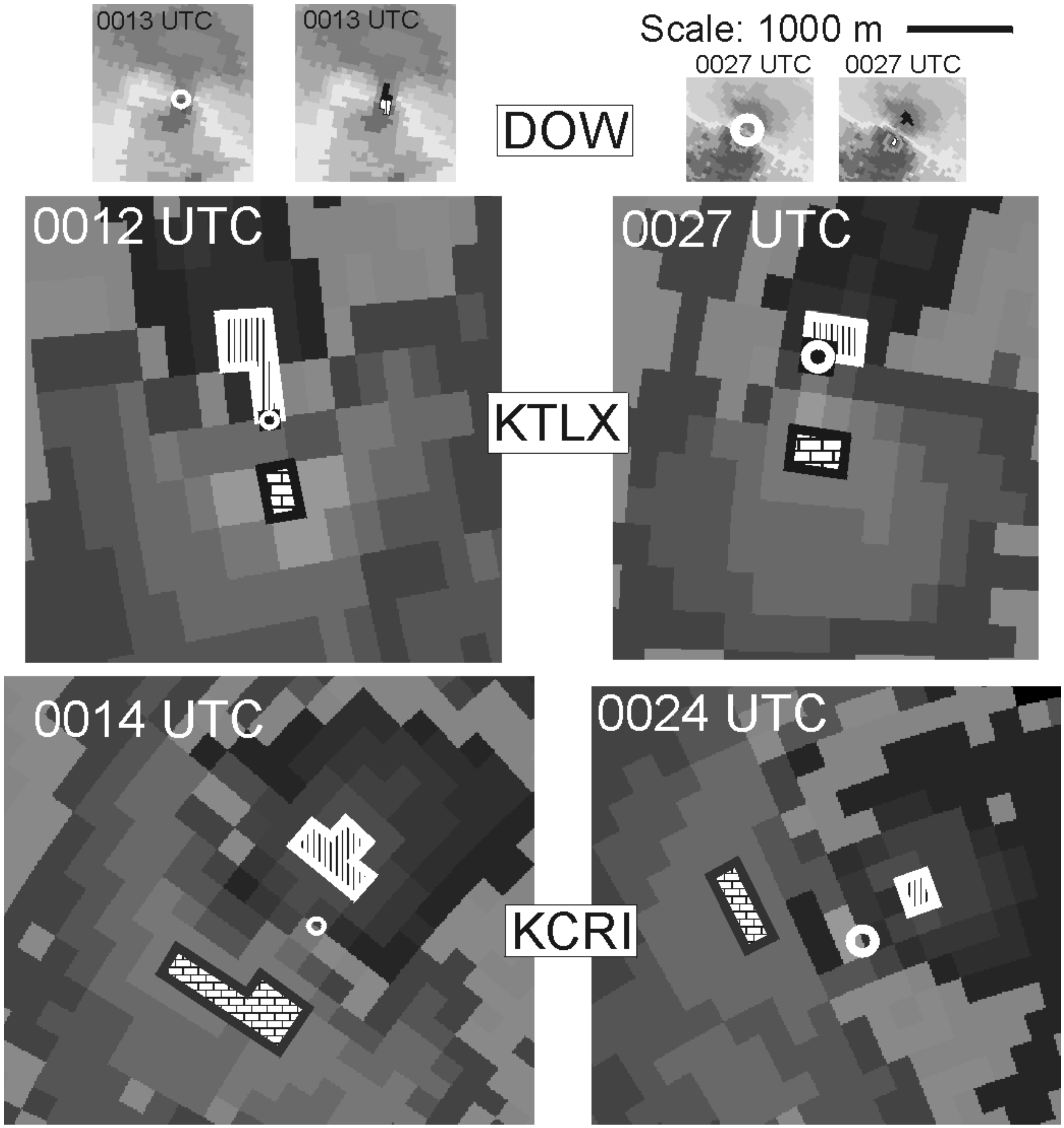

Figure 3. Scaled radar comparison for two different times. Radius of circle represents the radius of maximum wind as measured by the DOW. Velocity peaks are annotated. Beam heights range from 100m to 300m above radar level. The viewing direction of the DOW is generally to the east-southeast; the viewing direction of KTLX is generally toward the west; the viewing direction of KCRI is generally toward the northwest.