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NWA *EJOM* Images of Note

Radar Tornadic Debris Signatures on 27 April 2011

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1. Introduction

A historic tornado outbreak occurred across the southeastern United States on 25–28 April 2011 (NSSL 2011; NWS 2011). Radar tornadic debris signatures (TDSs; Ryzhkov et al. 2002, 2005; Kumjian and Ryzhkov 2008)—colloquially know as debris balls—were apparent with many of the tornadic storms on 27 April. Indeed, several television meteorologists highlighted these so-called debris balls during their live broadcasts (see examples from ABC 33/40 and The Weather Channel), which likely enhanced awareness of the imminent danger and consequently encouraged people to seek shelter.

Radar TDSs can be identified using the combination of reflectivity factor at horizontal polarization (Z_H), storm-relative velocity (SRV), differential reflectivity (Z_{DR}), and cross-correlation coefficient (ρ_{hv})—ρ_{hv} being the most powerful (Ryzhkov et al. 2005; Kumjian and Ryzhkov 2008). TDSs can contain substantial anthropogenic and biomass debris—in addition to hydrometeors (Dowell et al. 2005)—and this produces large backscatter with random orientations (Ryzhkov et al. 2005). Without Z_{DR} and ρ_{hv} (polarimetric variables), ground truth information is required to verify TDSs from Z_H and SRV data. The purpose of this note is to (i) show that TDSs were readily apparent on 27 April 2011, even when using only single-polarization radar data, and (ii) highlight the limitation of using only Z_H and SRV to identify TDSs.

2. Discussion

Data from the Weather Service Radar-1988 Doppler (WSR-88D) located 39 km (21 nm) south of Birmingham, Alabama (KBMX), were examined for potential TDSs from 1702–0457 UTC 27–28 April 2011; at least 77 suspected TDSs comprising seven separate events were found (Fig. 1). Tornadic damage of EF3–EF5 (e.g., Doswell et al. 2009) was associated with each of these TDS events (NWS 2011). Conversely, nine EF0–EF2 tornadic events were investigated and they did not display TDSs. This is consistent with Ryzhkov et al. (2005) who suggested that ≥EF3 damage is needed for a TDS to be observed. Nevertheless, one EF3 tornado occurred that did not exhibit a TDS. This EF3 tornado, however, occurred 119 km (64 nm) northwest of KBMX (83rd percentile distance of all 77 suspected TDSs), only lasted 8 min, and remained in relatively rural areas with no known fatalities or injuries. The horizontal limit of TDS detection was 148–167 km (80–90 nm), and this corresponds to a standard atmospheric height of 2.6–3.1 km (8.5–10.1 kft), which is in general agreement with Ryzhkov et al.'s (2005) vertical extent of 1–3 km.

A distinctive feature of the TDS is a relative maximum in Z_H centered near the tip of the hook echo (Fig. 1, column 1); the TDSs in Fig. 1 are from when damage was occurring. The TDS is not to be

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confused with the descending reflectivity core, which may *precede* tornadogenesis (Rasmussen et al. 2006). In addition, because of centrifuging the TDS is an overestimate of tornado width by a few to several core radii (Dowell et al. 2005). The average maximum Z_H for our 77 TDS samples is 62 dBZ, with a range of 51–72 dBZ. Ryzhkov et al. (2005) suggested a range of Z_H from 45–55 dBZ to define a TDS (based on storms in Oklahoma), but they analyzed pixels of 0.5 km × 0.5 km, and furthermore, may have had a negative bias to their Z_H because of partial beam blockage. The WSR-88D super-resolution data (Brown et al. 2005) from KBMX resulted in some smaller pixel sizes of 0.25 km × 0.38 km. Indeed, comparison of super-resolution to non-super-resolution radar data for other TDSs indicates an average 5-dBZ enhancement in the super-resolution TDSs.

In addition to the tornadic damage, a tornadic vortex signature (TVS) was associated with all of the identified TDSs (Fig. 1, column 2). The TVS always preceded the TDS, but not all TVSs were associated with TDSs (e.g., the aforementioned EF3 tornado northwest of KBMX). Obviously, a TVS is more important than a TDS when *anticipating* a tornado because not all storms produce a TDS—even though the presence of a TVS strongly suggests a tornado is ongoing. The Van Wert, Ohio, tornado (EF4, 10 November 2002) and Evansville, Indiana, tornado (EF3, 6 November 2005) are two notable examples of tornadoes rated EF3 or greater that had TVSs but no discernable TDSs. Conversely, features that appeared as TDSs (using single-polarization radar) were found with nontornadic storms (e.g., 1915 UTC 27 April northwest of KBMX); these features could be a concentrated region of raindrops (Dowell et al. 2005).

Another common feature of the TDS is the upward extension of the high values of Z_H (Fig. 1, column 3; also see Dowell et al. 2005). Cross sections of the TDSs revealed a tendency for the greatest Z_H to be near the ground—gradually decreasing with height; this is consistent with debris being lofted from the ground. Thus, in addition to the plan-view Z_H and SRV signatures, 2- and 3-dimensional displays of Z_H can aid in TDS identification. The vertical extent of the debris is difficult to ascertain, however, without the aid of polarimetric information.

A rather intriguing finding when evaluating other radar data was the simultaneous appearance of two TDSs within the same storm (Fig. 2). Ground truth and SRV information suggest the eastern TDS was genuine based on EF4 damage and intense azimuthal shear (0.117 s^{-1}) in the presence of a Z_H maximum; spectrum width also was maximized at the location of the eastern TDS and TVS. [Although spectrum width was >15 m s^{-1} (30 kts) for 68% of the 77 suspected TDSs, spectrum width offered little discerning value beyond Z_H and SRV.] The western TDS was located where an anticyclonic tornado would be expected (see Fig. 5 in Markowski 2002), but the absolute value of the shear was weaker (0.008 s^{-1}). There are no reports of an anticyclonic tornado, so we speculate debris was lofted by the eastern EF4 tornado, wrapped cyclonically around the tornado to the west, and then entrained into a nominal anticyclonic circulation. Debris can take tens of minutes to sediment to the ground, and have a propensity to fall to the left and rear of the tornadic circulation (Magsig and Snow 1998), which supports our speculation. Unfortunately, without concurrent Z_{DR} and ρ_{hv} data, the western TDS cannot be unequivocally confirmed.

3. Summary

Several TDSs were evident from KBMX—and other nearby radars—for storms that occurred during the historic outbreak on 27 April 2011. The reasons for the large number of TDSs are the (1) strength of the tornadoes, (2) substantial damage produced, and (3) upgrade of the WSR-88D to super-resolution in the late 2000s. TDSs can be identified with single-polarization radar data when paired with corroborating ground truth information. But even in the absence of ground truth data, TDSs are highly probable when a strong TVS is followed by the development of a localized maximum in Z_H near the tip of a hook echo after traversing a city or dense forest. However, considering the examples from 27 April 2011, confirmation of a TDS based on Z_H alone is not warranted.

There are times when a TDS is not evident for EF3–EF5 tornadoes when using only Z_H and SRV data because of distance from the radar, interference from precipitation, or lack of debris sources (e.g., WDTB 2011). In other cases, TDS-like signatures are present for nontornadic storms. The eventual dual-polarization data from the WSR-88D network will facilitate easier identification of TDSs, especially those that may be obscured by heavy precipitation or are on the lower threshold of detection using Z_H. In the meantime, the increasingly well-known term of debris ball should be used with care to avoid overuse and desensitization of the public.

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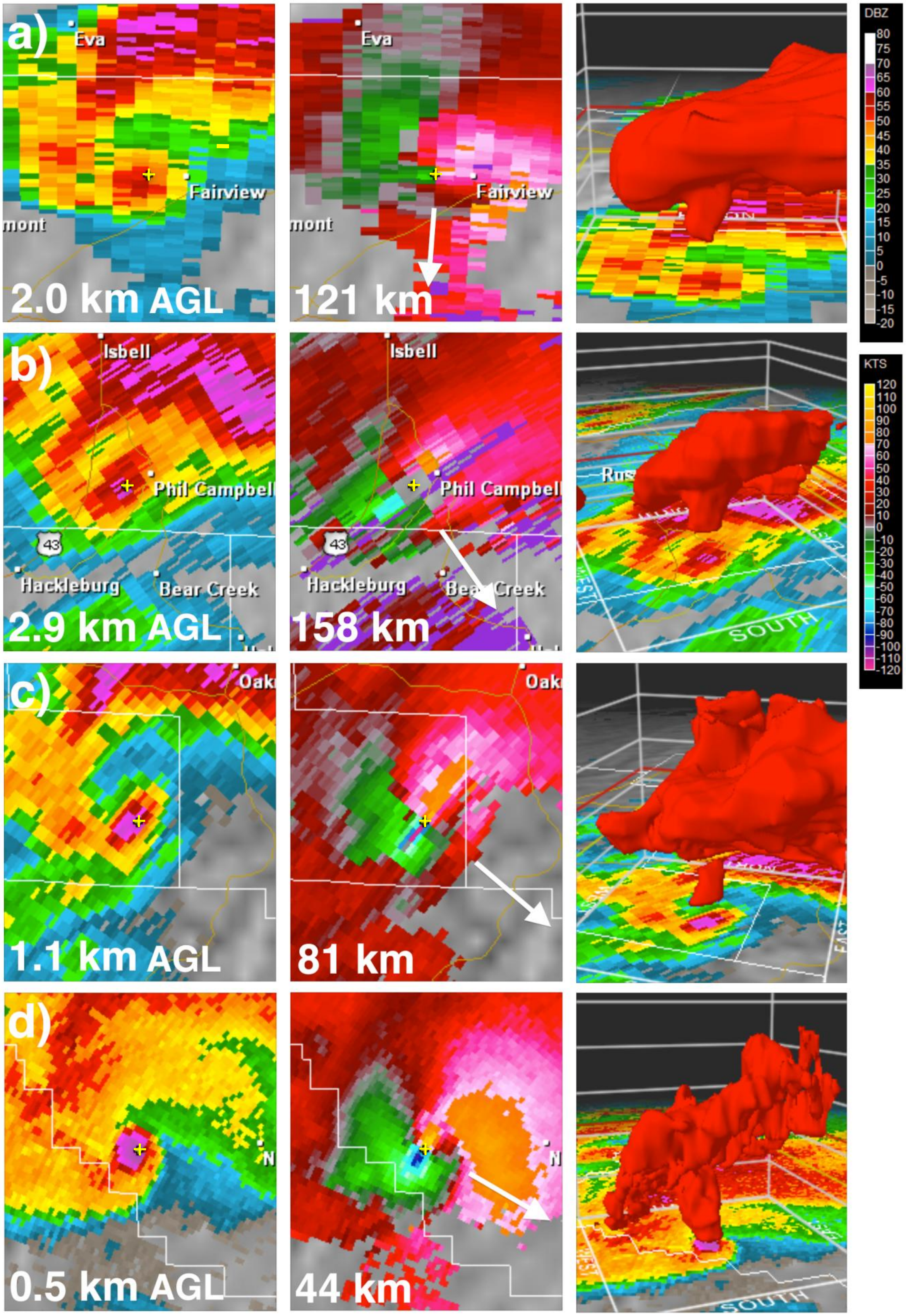
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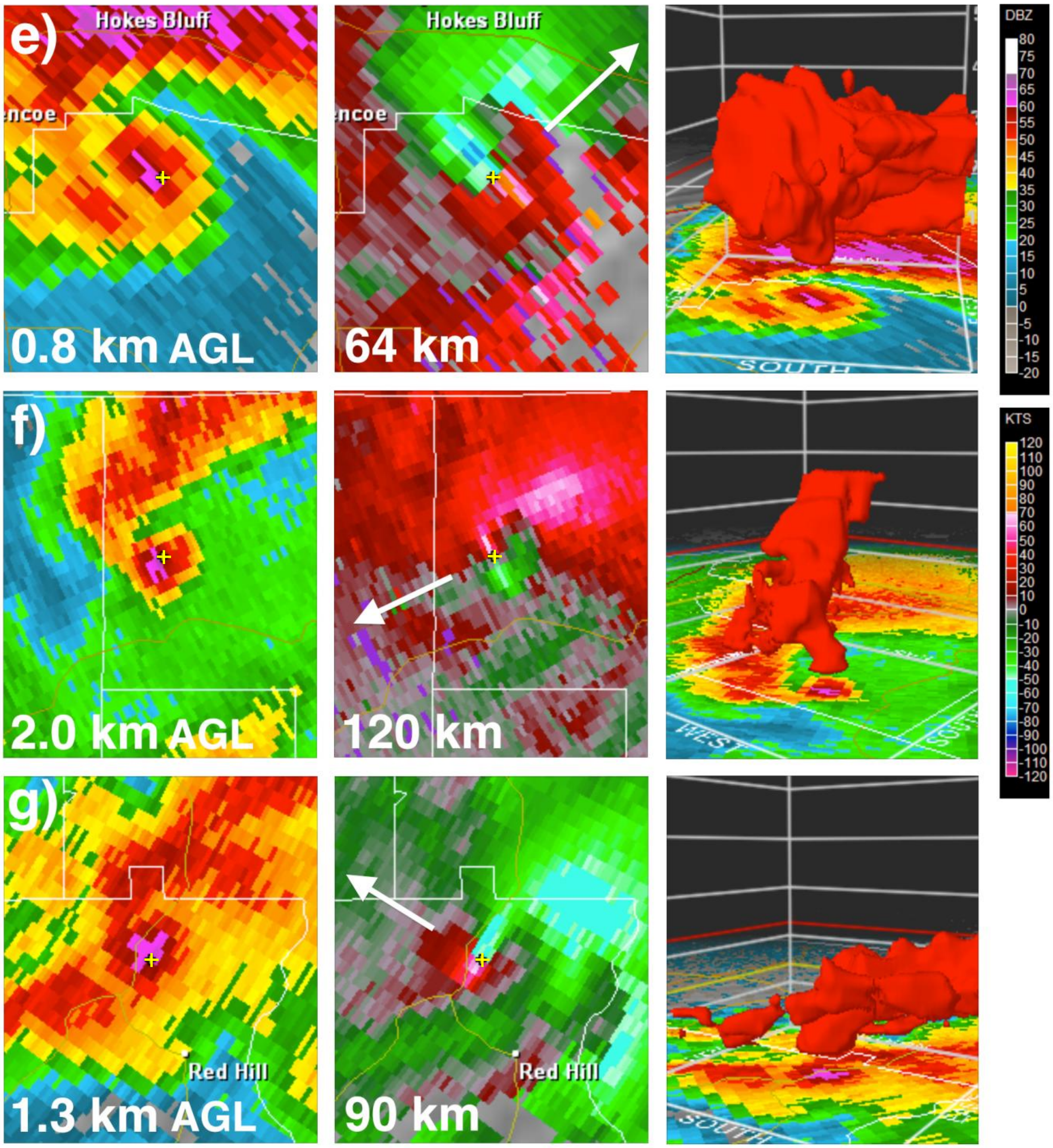

Figure 1. Seven representative TDSs identified from seven separate tornado events using the KBMX radar on 27–28 April 2011: 0.5° reflectivity (column 1); 0.5° storm-relative velocity (column 2); and 3-dimentional 55-dBZ isoecho (column 3). The spatial extent along the x-axis for the first two columns is 15.4 km (8.3 nm) and for the y-axis is 17.8 km (9.6 nm). Times are (a) 2006 UTC, (b) 2033 UTC, (c) 2134 UTC, (d) 2238 UTC, (e) 2323 UTC, (f) 0018 UTC, and (g) 0131 UTC. Yellow plus signs are centered on the tornadic vortex signatures (TVSs). Values in lower left of first column indicate the height of the TVS above ground level (AGL). Values in lower left of second column indicate the distance of the TVS from the radar, with arrow pointing toward the radar. Clicking on each row will link to NWS damage survey summaries.

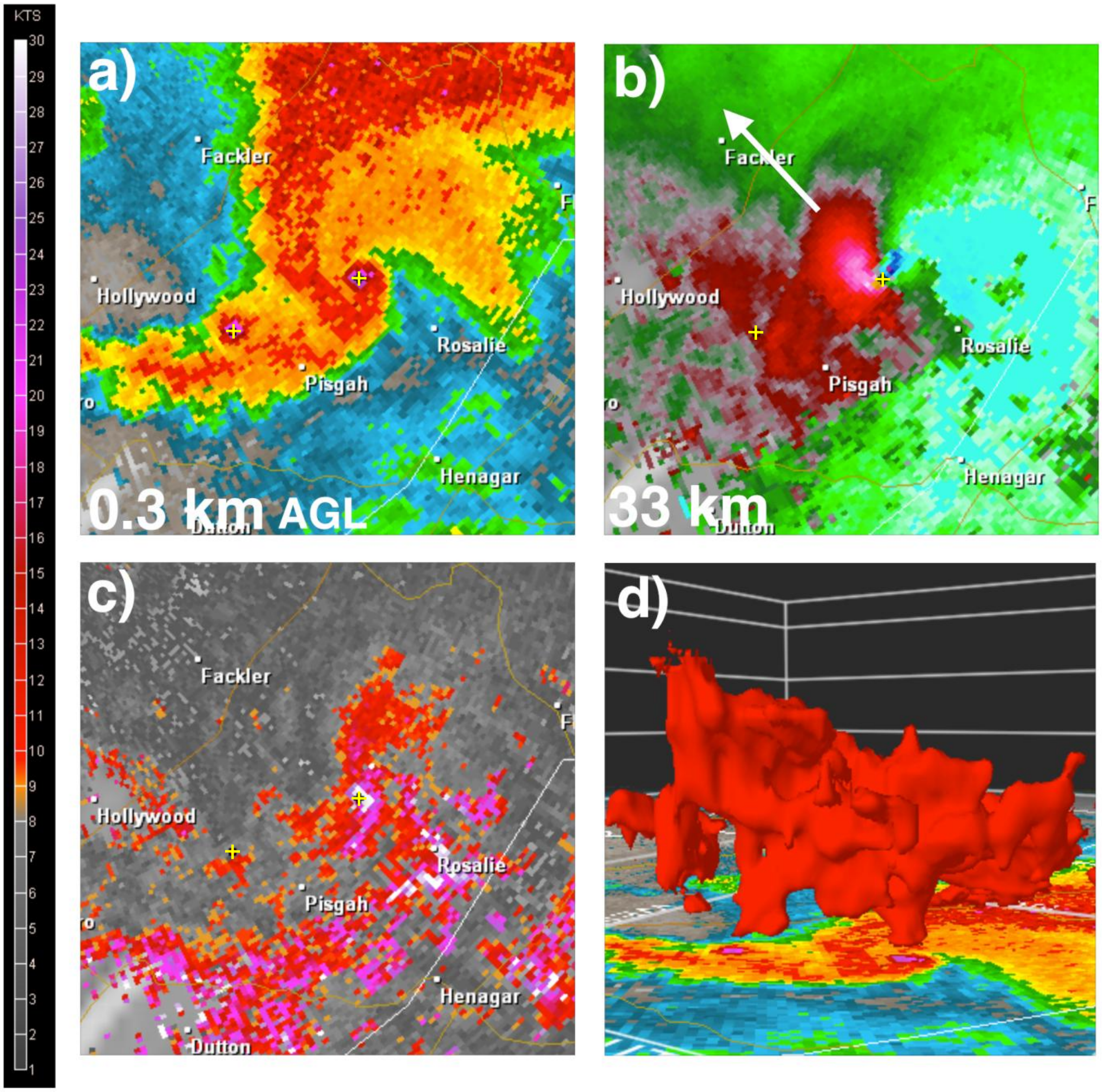

Figure 2. (a) Base radar reflectivity, (b) storm-relative velocity, and (c) spectrum width at 0.5° (scale at left), along with (d) the 55-dBZ isoecho, at 2116 UTC 27 April 2011 from the Huntsville, Alabama (KHTX), WSR-88D. The horizontal and vertical extents for (a)–(c) are 27 km (14.6 nm). Yellow plus signs on the base images indicate potential TDSs. Text annotation as in Fig. 1, with values for the eastern TDS only. Clicking the image will link to the NWS damage survey summary.