# 15.5 PRECIPITATION PROPERTIES OF A COOL-SEASON TORNADIC STORM INFERRED FROM C-BAND DUAL-POLARIMETRIC RADAR AND 2D-VIDEO DISDROMETER OBSERVATIONS

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## 1. OBSERVATIONS

A cool-season severe storm produced an EF-2 tornado and isolated small (< 2.5 cm) hail reports in and around downtown Huntsville, Alabama during the early evening hours of 21 January 2010. Just prior to tornado touchdown, the storm passed directly over a bermed research area heavily instrumented to measure precipitation properties, including a Compact 2D-Video Disdrometer (2DVD). Storm evolution was well observed by the Advanced Radar for Meteorological and Operational Research (ARMOR). ARMOR is a C-band dual-polarimetric Doppler radar located at the Huntsville International Airport, which is about 14 km southwest of the disdrometers. ARMOR sampled low-to-mid levels (0-4 km) of the storm at close range (5-25 km) every 1-3 minutes leading up to and including tornado touchdown.

ARMOR (horizontal) radar reflectivity ($Z_h$) and differential reflectivity ($Z_{dr}$) observations are corrected for attenuation and differential attenuation, respectively, using a self-consistent method with polarimetric constraints (Bringi et al. 2001). Relative calibration is achieved using vertically pointing scans in drizzle and light rain. Absolute calibration is maintained using the polarimetric self-consistency approach of Ryzhkov et al. (2005) and cross-comparisons with the nearby operational Hytop (KHTX) Weather Surveillance Radar – 1988 Doppler.

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## 2. PRECIPITATION PROPERTIES

Precipitation properties, including drop size distribution (DSD), shape and type, are inferred from the 2DVD, ARMOR and storm report observations of the tornadic event. The key result confirmed by all observations is the predominance of low concentrations of very large raindrops, likely resulting from the melting of small hail, throughout most of the low-to-mid level echo.

Unlike some other tornadic supercells documented in the literature, the $Z_{dr}$ was routinely in the range of 3-5 dB and 5-8 dB was not uncommon in the high reflectivity echo ($Z_h$ > 45 dBZ) of the entire forward flank downdraft (FFD) (Figure 1). A $Z_{dr}$-arc, or enhanced (5-8 dB) region of $Z_{dr}$ in a cyclonically curved pattern, was consistently present along the southern flank of the FFD prior to and during tornado touchdown. The $Z_{dr}$-arc (or $Z_{dr}$-shield) has been associated with the presence of very large, oblate raindrops and a relative lack of smaller drops (Kumjian and Ryzhkov 2008; Romine et al 2008). In order to produce such a modified DSD, size sorting of raindrops likely occurs. Due to the increase in speed and veering of the storm-relative winds with height in environments supporting right-moving supercells, smaller raindrops, which fall with smaller terminal velocities, are advected farther from their source region than the larger raindrops, which fall faster (Kumjian and Ryzhkov 2008). At C-band, the very large $Z_{dr}$ values in the $Z_{dr}$-arc region have been attributed to resonant sized (5-8 mm) rain drops and melting hail (Kumjian and Ryzhkov 2008).

For the first time, 2DVD observations confirm that the FFD and $Z_{dr}$-arc regions of a tornadic supercell were indeed composed of large raindrops with mass weighted mean diameters ($D_m$) of 3 mm and maximum rain drop sizes of over 5-6 mm (Figure 2). Drop concentrations (50-1100 $m^{-3}$) and rain rates (2-24 mm $h^{-1}$) from the 2DVD were unusually low throughout the entire FFD and especially $Z_{dr}$-arc regions. Gamma fits to the 2DVD PSDs (Figure 3) clearly indicate negative shape parameters, which has also been associated with size sorting in the presence of shear (Dingle and Hardy 1962). 2DVD drop shapes are consistent with large oblate raindrops (not shown).

ARMOR (C-band) $Z_{dr}$ in the range of 5-8 dB (Figure 1) in the $Z_{dr}$-arc region is consistent with the presence of resonant sized rain drops measured by the 2DVD there (Figures 2 and 3). Only two hail reports (1.3 cm and 2.2 cm) came from storm spotters for the entire event. $Z_{dr}$ in the area of melting hail was also from 3-7 dB near the surface (not shown), making it difficult to differentiate hail from large raindrops in the ARMOR observations.

A precipitation streamer (in 2D) or sheet (in 3D) was present at low levels on the rear flank of the tornadic storm prior to tornadogenesis (2317 UTC[1]). The narrow streamer was a rearward lateral extension of the larger and broader $Z_{dr}$-arc region (Figure 4). The streamer was characterized by very large $Z_{dr}$ (3-8 dB) and typically low $Z_h$ (< 30 dBZ), suggesting extremely low concentrations of large raindrops or melting hail at low levels. Its presence was most evident in $Z_{dr}$ (and was not always as clear in $Z_h$). This "$Z_{dr}$-streamer" wrapped up cyclonically in the mesocyclonic flow and later evolved into (or became part of) the classic $Z_h$ tornado appendage/hook echo that was apparent at low levels prior to and during tornado touchdown. The correlation coefficient ($\rho_{HV}$) in the $Z_{dr}$-streamer was generally high ($\rho_{HV}$ > 0.9) suggesting that the feature was comprised of oblate, large (resonant sized) rain drops. At the tip of the hook echo, the tornado signature in radial velocity ($V_r$) is accompanied by a local maximum in $Z_h$ (25-35 dBZ) with generally low $Z_{dr}$ (-1 to 2 dB) and suppressed $\rho_{HV}$ (0.6 to 0.8) (see R4 and R5 of Figure 4).

[1] Huntsville, AL National Weather Service Weather Forecast Office Storm Survey for the January 21, 2010 Huntsville EF-2 Tornado/Severe Weather Event: http://www.srh.noaa.gov/hun/?n=hunsur_2010-01-21

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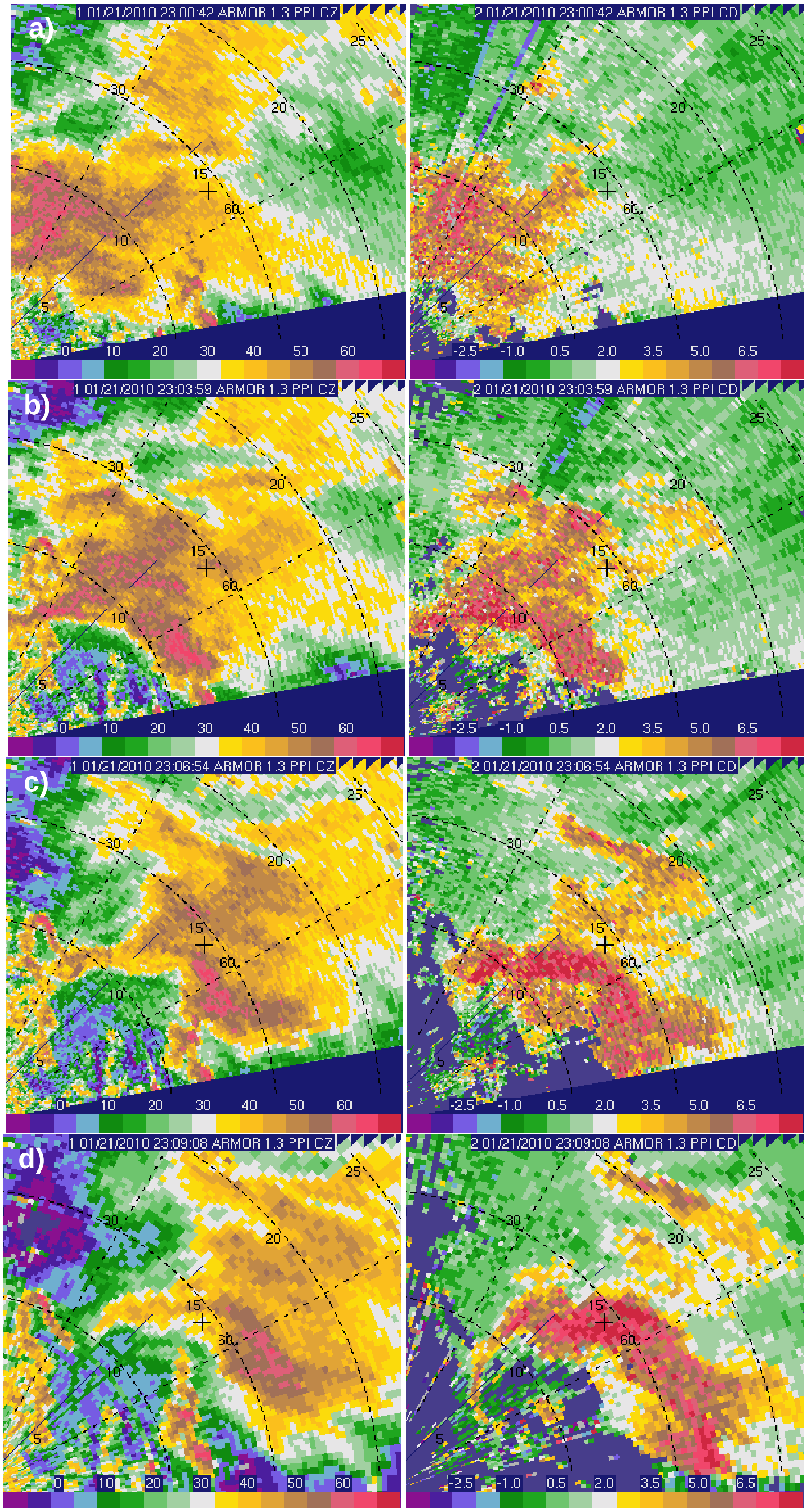


**Figure 1.** ARMOR low-level (1.3°) PPI images shown in the *left* column of attenuation corrected $Z_h$ (dBZ, color shaded as shown) and in the *right* column of differential attenuation corrected $Z_{dr}$ (dB, color shaded as shown) on 21 January 2010 at a) 23:00:42 UTC, b) 23:03:59 UTC, c) 23:06:54 UTC, d) 23:09:08 UTC. Range rings (azimuth lines) are shown every 5 km (30°). The "+" symbol at range 14.4 km and azimuth of 52.7° is the location of the 2DVD unit at NSSTC.

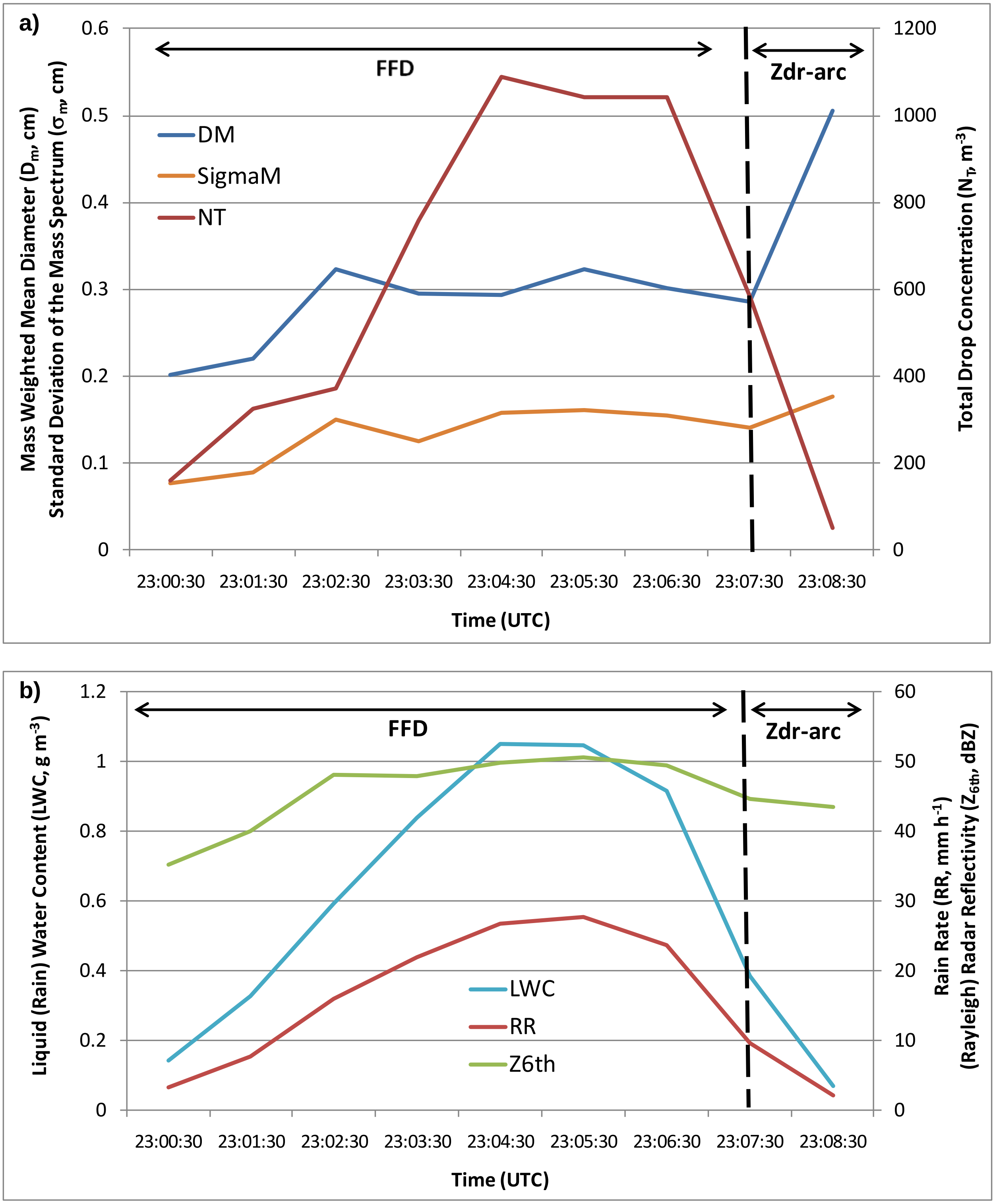


**Figure 2.** Evolution of 1-minute 2DVD DSD properties and moments on 21 January 2010 from 2300 UTC to 2309 UTC as the supercell passed over NSSTC prior to tornado touchdown in Huntsville at 2317 UTC. a) Mass weighted mean diameter ($D_m$, cm), standard deviation of the mass spectrum ($\sigma_m$, cm), and total drop concentration ($N_t$, $m^{-3}$). b) Liquid (rain) water content (g m-3), rain rate (mm $h^{-1}$), and Rayleigh radar reflectivity ($6^{th}$ moment of DSD) (dBZ). Properties and moments were calculated from 2DVD bin counts.

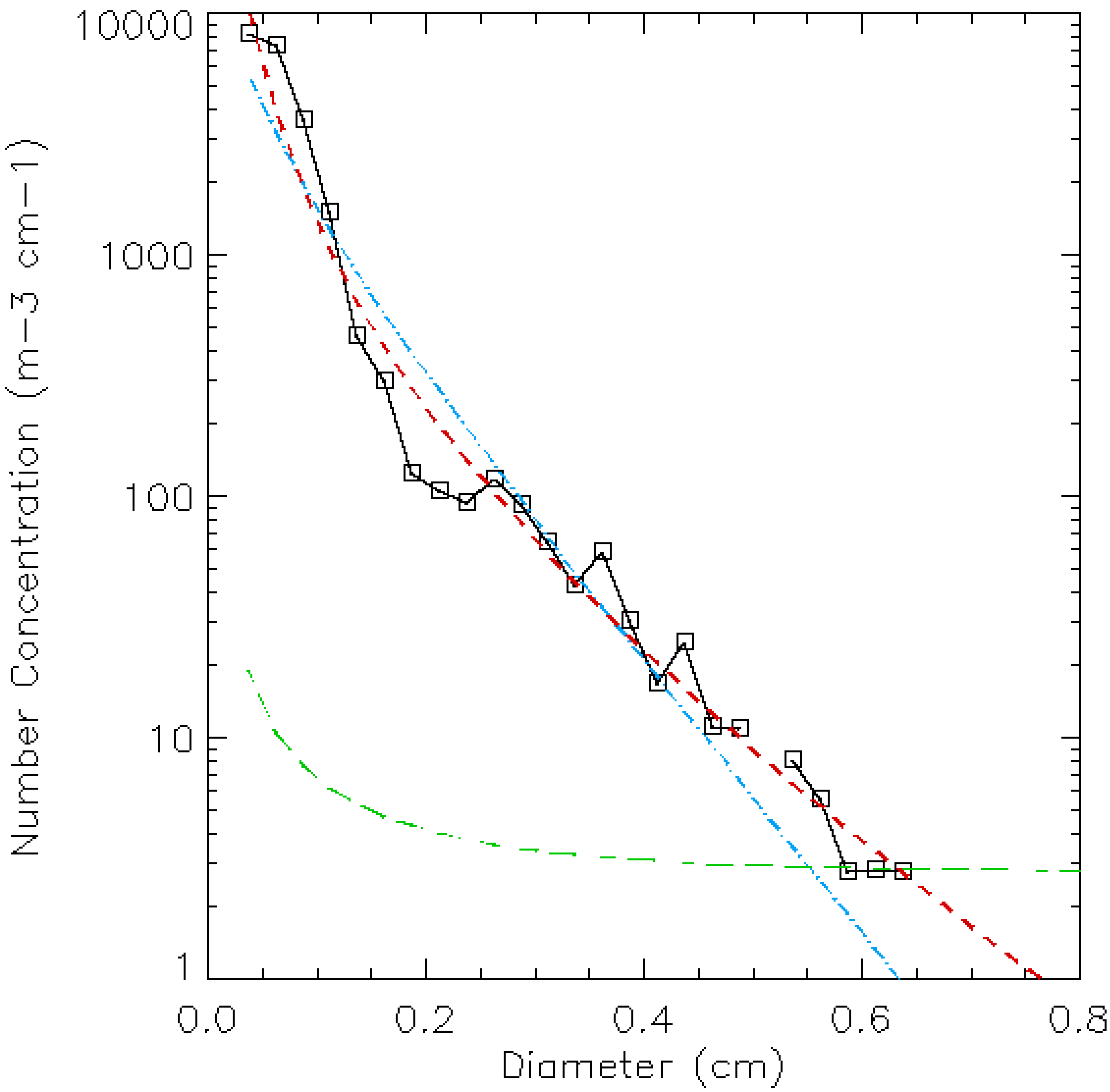


**Figure 3.** Three-minute (2306 – 2309 UTC) drop size distribution from the southern flank of the FFD and Zdr-arc regions of the tornadic supercell on 21 January 2010 over Huntsville, Alabama. The black line and solid squares are the drop bin counts for the three minute period. The blue dash-dot line is a gamma fit using the method of moments. The red dashed line is a gamma fit using the truncated method of moments (Ulbrich and Atlas 1998). The truncated method of moments provides a better fit to the bin count data and clearly shows the super-exponential shape ($\mu$ = -1.8) of the DSD in the FFD and Zdr-arc regions. The green dashed line represents the minimum possible drop count per bin during the sampling period (i.e., 1 drop per bin per 3-minute period). Note that the largest three diameter bins with a measured number concentration (Diameter $\geq$ 0.575 cm) fall on the minimum drop count line, suggesting that the large drop diameter tail is possibly under-sampled despite the 3-minute integration period.

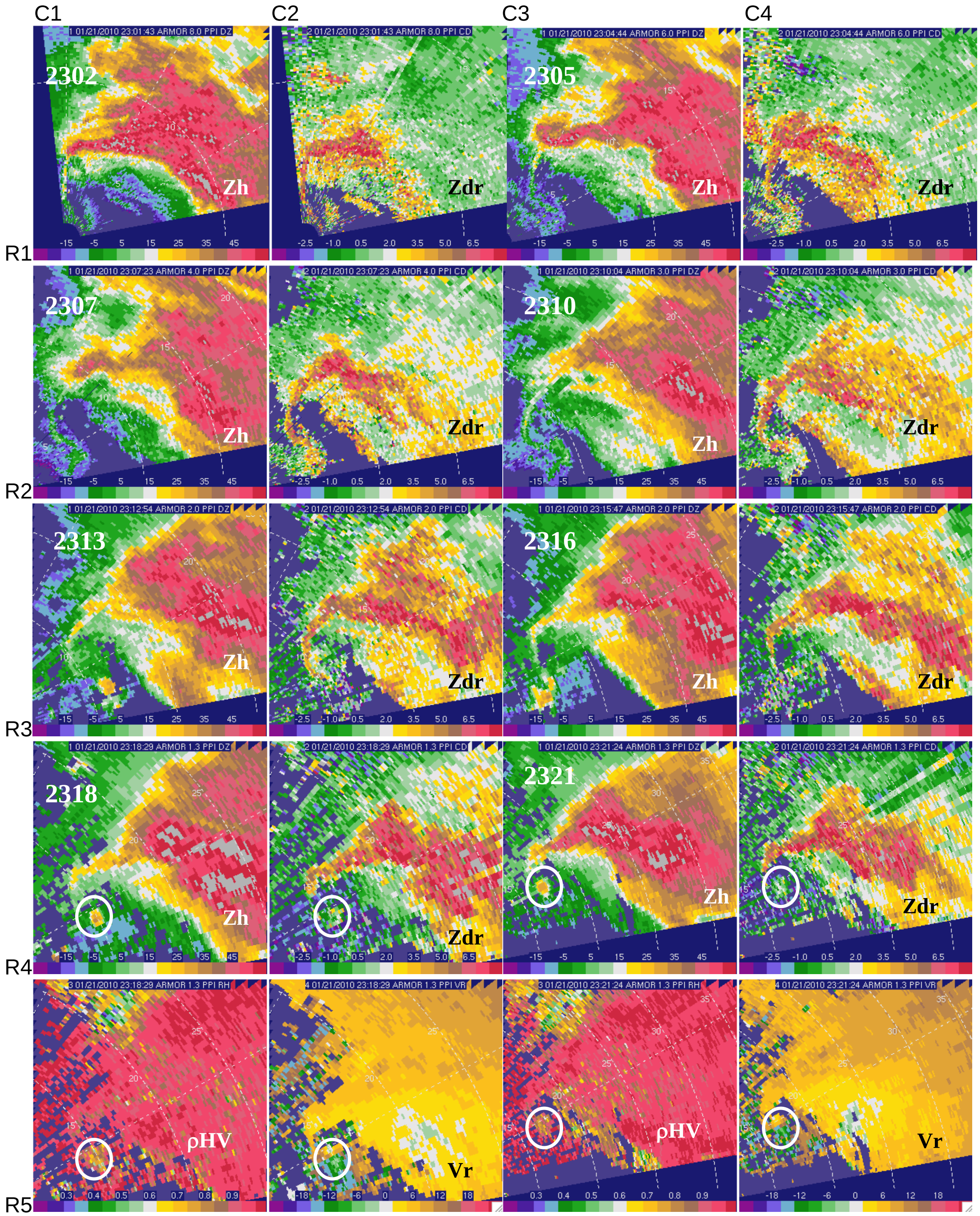


**Figure 4.** From R1 to R4, ARMOR PPI time series of $Z_h/Z_{dr}$ in C1/C2 and C3/C4 of the $Z_{dr}$-streamer evolving into a hook echo at low-levels (< 1 km AGL) from 2302 UTC to 2321 UTC (tornado touchdown = 2317 UTC). R1, C1/C2: 2301:43 UTC, 8.0°; R1, C3/C4: 23:04:44 UTC, 6.0°; R2, C1/C2: 2307:23 UTC, 4.0°; R2, C3/C4: 23:10:04 UTC, 3.0°; R3, C1/C2: 2312:54 UTC, 2.0°; R3, C3/C4: 23:15:47 UTC, 2.0°; R4, C1/C2: 2318:29 UTC, 1.3°; R4, C3/C4: 23:21:24 UTC, 1.3°. In R5, C1/C2 and C3/C4 are PPI images of $\rho_{HV}/V_r$ that correspond to the $Z_h/Z_{dr}$ PPI images in R4. Tornado in R4 and R5 is highlighted.