Rapid-scan, polarimetric, mobile Doppler radar observations at X-band of an EF-5 tornado in Oklahoma on 24 May 2011

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(Dated: 16 May 2012)

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1. Introduction

To study phenomena that have a short advective (or orbit) time scale such as tornadoes (~ 10 s), rapid updates are needed to document their development and evolution. Mobile Doppler radars that operate at X-band are well suited to probing tornadoes by getting very close to them. Those that also have rapid-scan capability, scan partially electronically and partially mechanically (Wurman 2001; Isom et al. 2009; Bluestein et al. 2010). French et al. (2012) have studied several tornadoes and their life cycle in detail with volumetric update times of just 6 – 14 s.

Both tornadic and non-tornadic supercells have been studied using polarimetric, fixed-sight S- and C-band Doppler radars, so that microphysical processes can be illuminated and tornado debris signatures identified (e.g., Kumjian and Ryzhkov 2008). Polarimetric, X-band mobile Doppler radars have also been used with the same objectives (e.g., Bluestein et al. 2007; Tanamachi et al. 2012: Snyder et al. 2011; 2012). However, to date, electronically scanning meteorological Doppler radars with polarimetric capability have not yet been implemented owing to technical challenges (Zhang et al. 2011).

In the meantime, Pazmany et al. (2011) have designed and implemented an X-band, mechanically scanning, rapid-scan, mobile Doppler radar with polarimetric capability (differential reflectivity Z_{dr} and co-polar cross-correlation coefficient ρ_{hv}). The purpose of this paper is to showcase some unique, rapid-scan, polarimetric measurements made at close range in an EF-5 tornado and its parent supercell.

2. Description of the radar

The truck-mounted radar (Fig. 1) named RaXPol (rapid-scan, X-band, polarimetric) can scan at a maximum azimuthal speed of 180^0 s^{-1}. Enough independent samples (12) to get good estimates of Doppler wind and polarimetric variables at this high rotational speed are obtained using frequency hopping (Pazmany et al. 2011). RaXPol is not as rapidly scanning as non-polarimetric, partially electronically scanning mobile Doppler radars like the rapid DOW (Wurman 2001), the MWR-05XP (Bluestein et al. 2010), or the AIR (Isom et al. 2009), but is much faster than other polarimetric mobile radars (e.g., Bluestein et al. 2007; Wurman et al. 2011).

Fig. 1. RaXPol, spring 2011 (from video frame © H. Bluestein)

3. Data collected

On 24 May 2011 data were collected with RaXPol during two deployments. One, southwest of El Reno, OK, included the dissipation of one tornado and the beginning of an EF-5 tornado (Figs. 3, 4) and its evolution to maturity (Fig. 2) over a 57 min time span. The second deployment (not shown) included another tornado at just 1.5 km range. There were also two deployments by the non-polarimetric, partially electronically scanning MWR-05XP (Bluestein et al. 2010) (not shown).

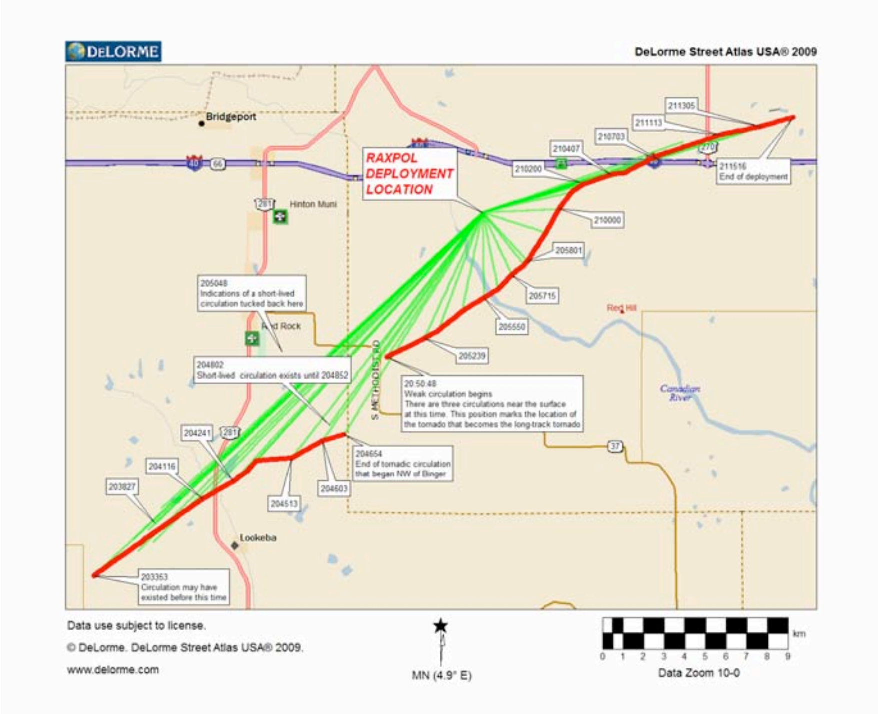

Fig. 2. Track of two of the tornadoes probed by RaXPol on 24 May 2011 and the deployment location of RaXPol.

Fig. 3. Tornado southwest of El Reno, OK on 24 May 2011, at ~ 2058 - 59 UTC. (© H. Bluestein)

Fig. 4. Damage from the tornado on 24 May 2011 inflicted while while RaXPol was scanning. Photograph taken on 25 May 2011. (© H. Bluestein)

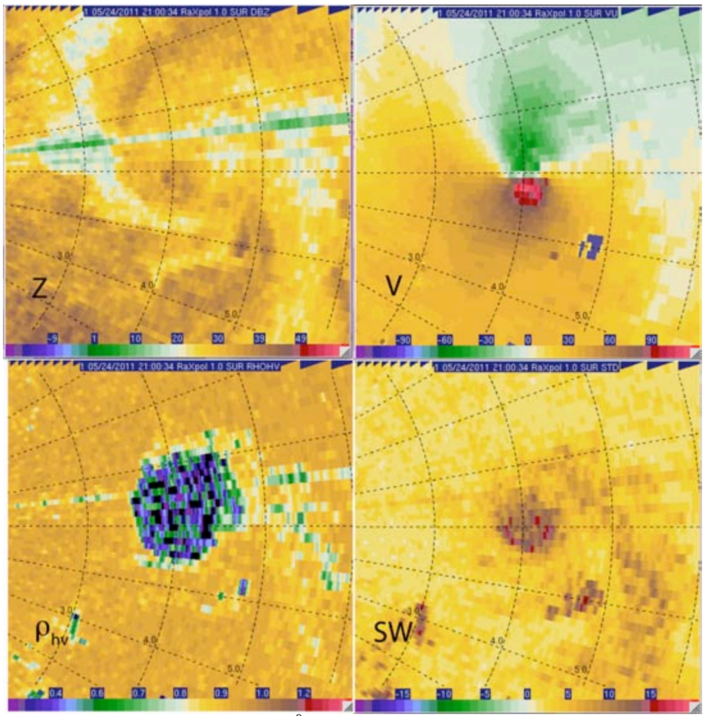

Fig. 5. Data collected by RaXPol on 24 May 2011 at 1^0 elevation angle (~ 70 m ARL), when the tornado was at its most intense (maximum Doppler velocity 125 m s^{-1}). Equivalent radar reflectivity factor in dBZ_e (upper left), unfolded Doppler velocity in m s^{-1} (upper right), co-polar correlation coefficient (lower left), spectrum width (lower right); Z_{dr} not shown here. Range rings every km.

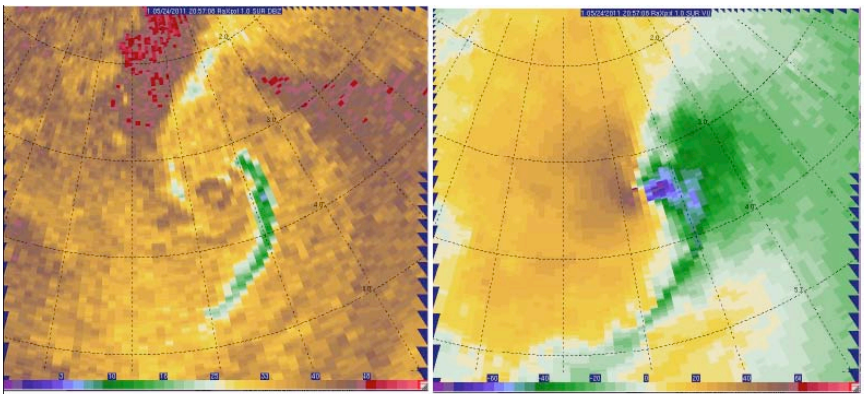

Fig. 6. Low-echo arc near tornado on 24 May 2011, at 2057:08 UTC, at 1^0 elevation angle; equivalent radar reflectivity factor in dBZ_e (left); unfolded Doppler velocity in m s^{-1} (right). Range rings shown every km.

When the tornado, having Doppler wind speeds of 125 m s^{-1} at about 70 m ARL (above radar level), was most intense, fields of equivalent radar reflectivity factor, Doppler velocity, co-polar cross correlation coefficient (ρ_{hv}), and spectrum width (Fig. 5) show a well-defined debris signature around the tornado at 4 km range. The wind measurement is the second-highest wind speed ever measured in a tornado by a Doppler radar; 135 m s^{-1} was measured in the Bridge Creek, OK tornado on 3 May 1999 (Wurman et al. 2007). A unique signature of a narrow low-reflectivity arc is seen just ahead of and trailing the tornado (Fig. 6).

The ability of the radar to document very rapid evolution in the wind field is demonstrated in Fig. 7; over only a 26 - s period, the approaching Doppler wind speeds increase with good temporal continuity from ~ 50 – 60 m s^{-1} to well over 80 m s^{-1}. On the storm scale, a well-defined bounded weak-echo region (BWER) is seen at midlevels, along with curved Z_{dr} bands and a ρ_{hv} arc. There is excellent temporal continuity in the low - ρ_{hv}, debris signature on 2-s time scales (Fig. 9). Some debris can be tracked around the tornado (e.g., "D" in Fig. 9). The debris signature is sometimes coincident with relatively high reflectivity at the center of the tornado, the "debris ball" (Fig. 10) and also a comma-shaped pattern (Fig. 9).

Vertical cross sections through the tornado (Fig. 11) display an echo-weak hole above 500 m and a 1-km wide debris signature (low ρ_{hv}) extending up to the top of the domain near 2 km ARL. The spectrum width is greatest below 500 m. The highest Doppler velocities are at low levels; the maxima in Doppler velocities lean radially outward with height.

4. Concluding comments

This dataset is, to the best of our knowledge, the first polarimetric, rapid-scan, mobile Doppler-radar dataset of an EF-5 tornado. The data are of high quality. Detailed analyses are now in progress and scientific results forthcoming.

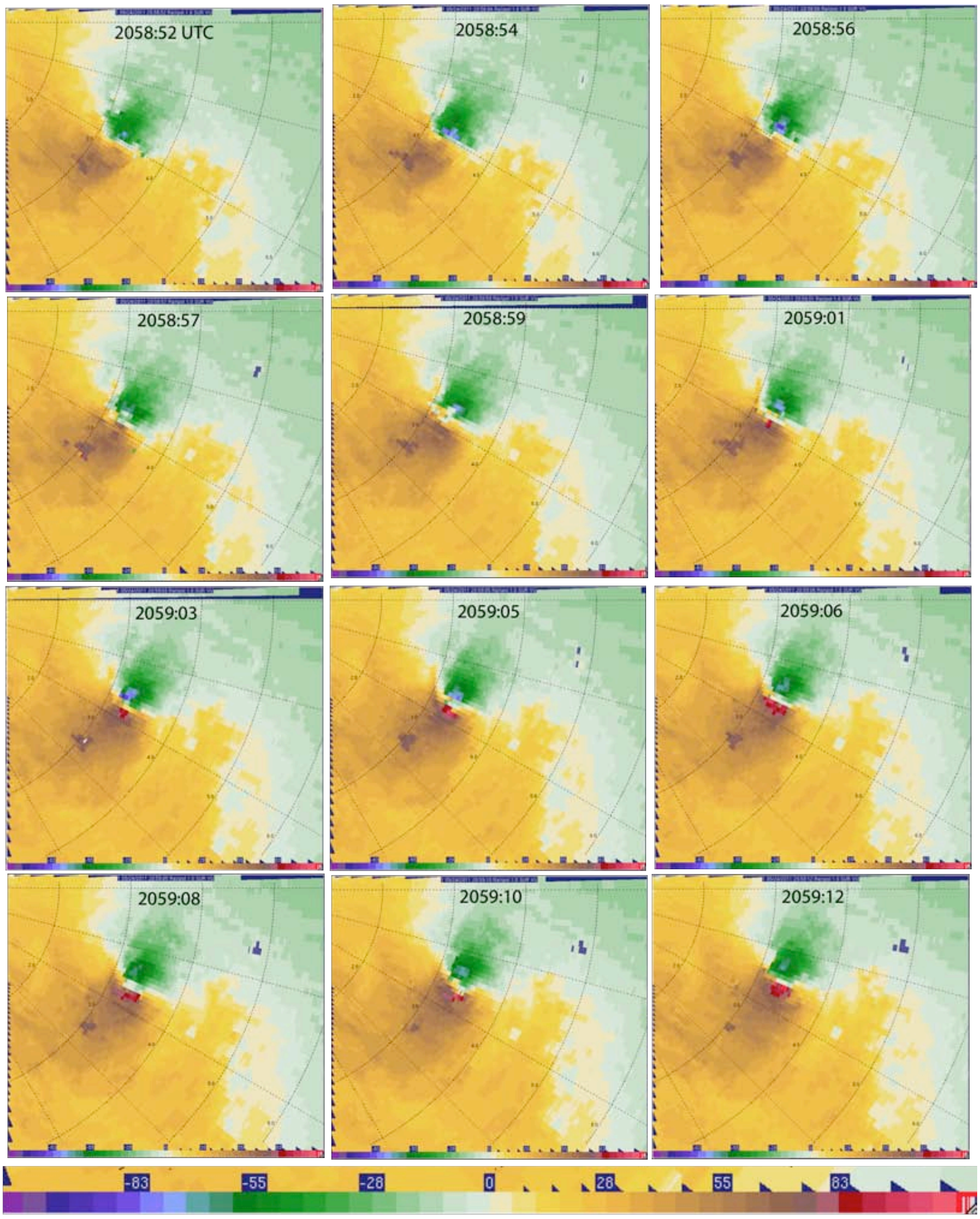

Fig. 7. Sequence of unfolded Doppler velocity field at 1^0 elevation angle over a 20 s period of a developing tornado, every ~2 s, from 2058:52 – 2059:12 UTC, 24 May 2011. Range rings shown every km. Doppler velocity color scale shown at the bottom in m s^{-1}.

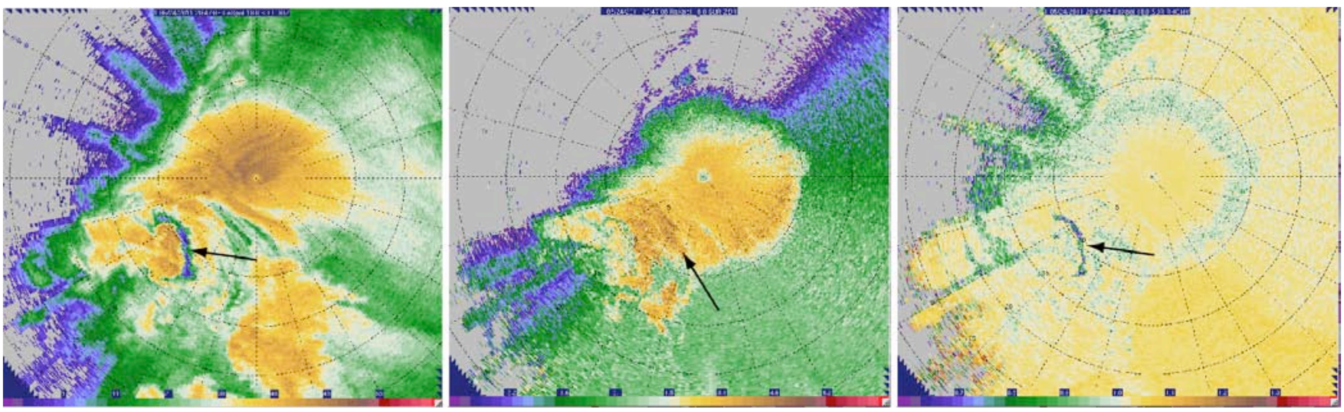

Fig. 8. Midlevel BEWR (left), curved Z_{dr} bands (middle), co-polar cross-correlation (ρ_{hv}) arc (right) at 2047:08 UTC on 24 May 2011, at 18^0 elevation angle (~ 3 km ARL). Range rings shown every 5 km. Arrows point to feature.

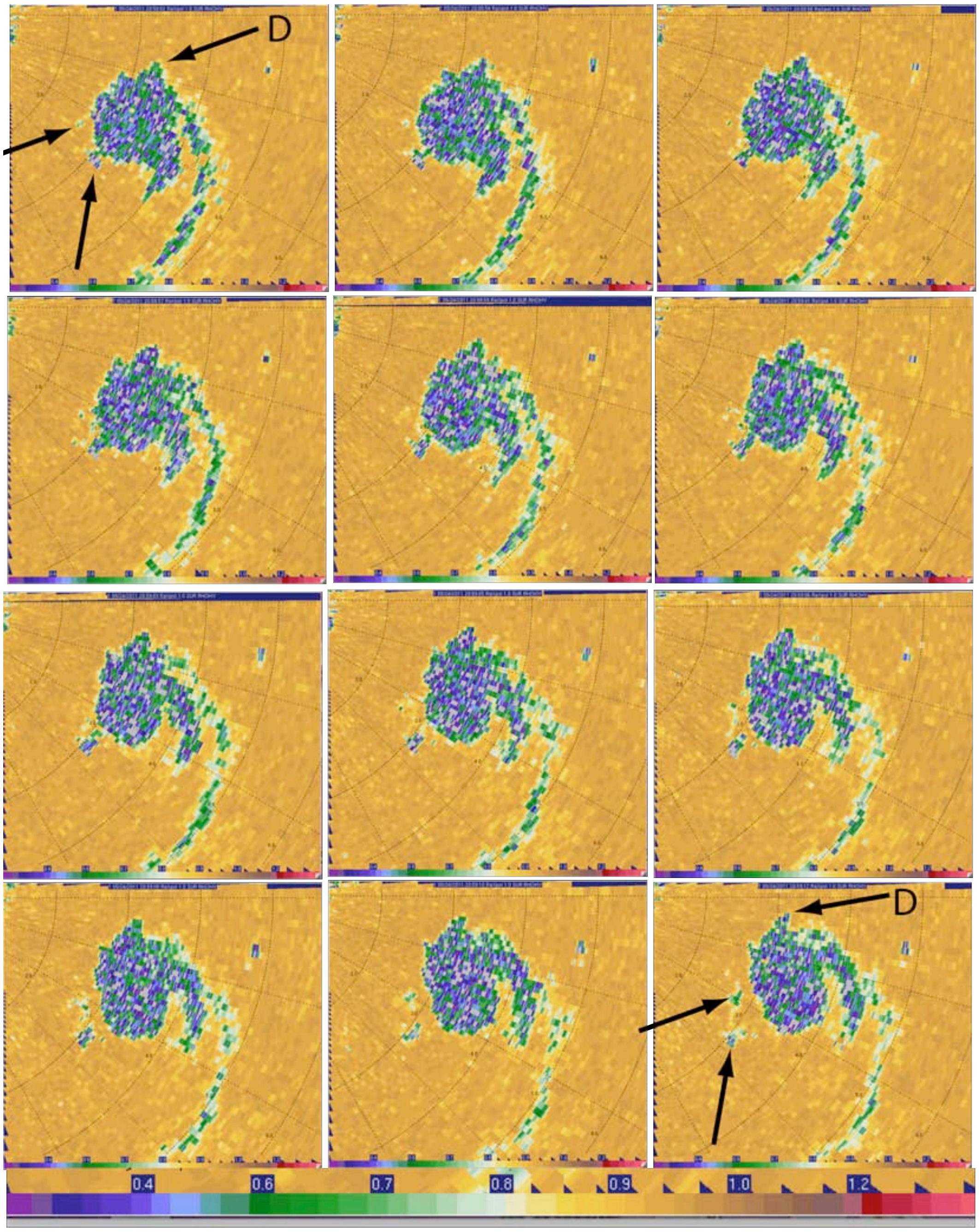

Fig. 9. As in Fig. 8, but for co-polar cross-correlation coefficient ρ_{hv}. "D" marks trackable debris; other two arrows indicate stationary, apparent ground targets. Low values mark debris ball and arcs of debris.

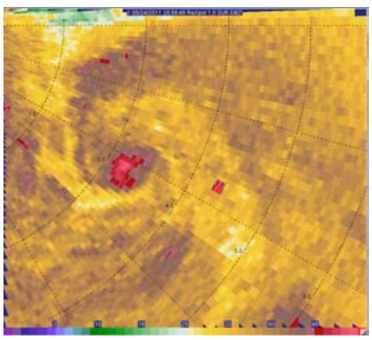

Fig. 10. Debris ball. Equivalent radar reflectivity factor in dBZ_e for second panels in Figs.7 and 9.

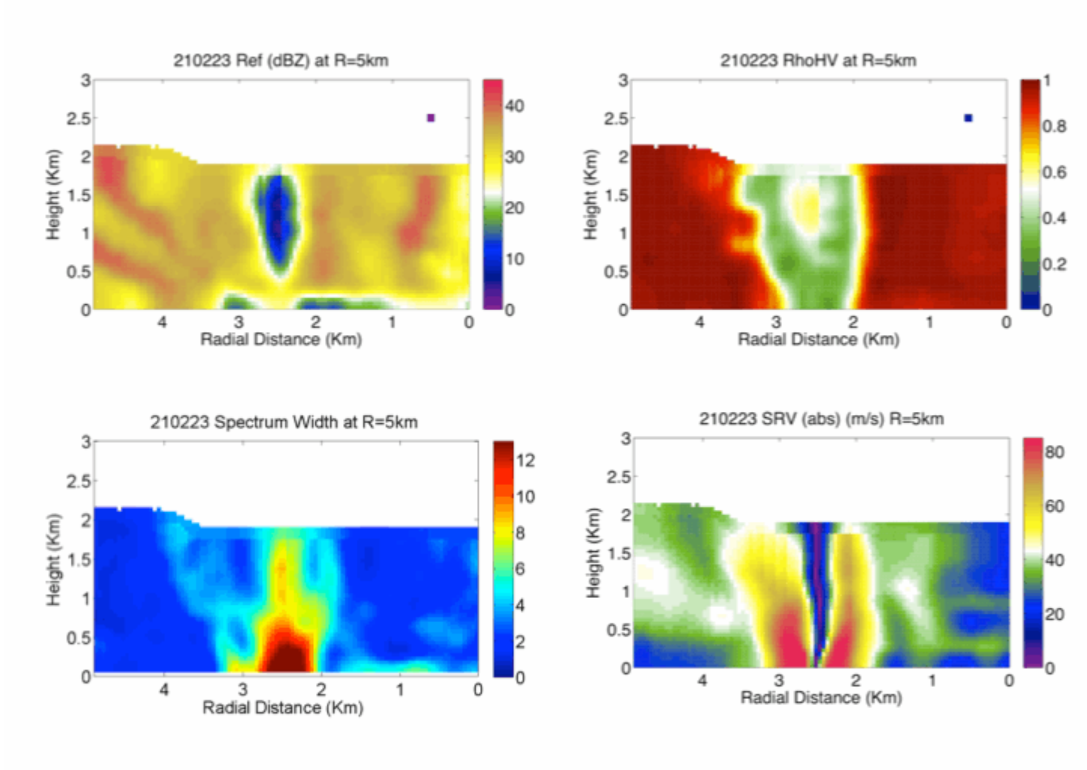

Fig. 11. Vertical cross sections (distance normal to the beam at a constant range vs. height) in km of equivalent radar reflectivity factor in dBZ (upper left), co-polar cross-correlation coefficient (upper right), spectrum width in m s^{-1} (lower left), and absolute value of storm-relative Doppler velocity in m s^{-1} (lower right), at 2102:23 UTC on 24 May 2011. From RaXPol data at 5 km range.

Acknowledgments

This study was supported by the National Science Foundation MRI Grant ATM-0821231 and Grant ATM-0934307 to the University of Oklahoma. We also thank John Meier and Bob Palmer (OU ARRC) for maintaining the radar and providing space for its storage

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