Some Considerations for the Use of High-Resolution Mobile Radar Data in EF-Scale Assessments

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Introduction

Since 2011, graduate students and faculty at the University of Oklahoma have used RaXPol (Pazmany et al. 2013) – a rapid-scan, polarimetric, mobile radar – to collect data of tornadoes, supercells, and related phenomena in the central United States. On 31 May 2013, RaXPol sampled a multiple-vortex tornado in El Reno, OK, with radial velocities (V_R) exceeding 135 m s^{-1}. Several of the observed subvortices moved at speeds of 75-80 m s^{-1}, limiting the duration of time the extraordinarily strong winds were experienced at any one location. There is great uncertainty, however, regarding how the observed V_R relates to a *3 second, ~10 m AGL wind speed* standard such as that used in the Enhanced Fujita (EF) Scale. In addition, differential radial velocity (V_D), defined as the difference between the V_R calculated using the H channel (V_H) and that calculated using the V channel (V_V), within several intense tornadoes is shown. Large V_D tends to be associated with high σ_v and low ρ_{hv}, not surprising given the increased variance in the velocity estimates expected when those two conditions are observed. More details and discussion of these data can be found in Snyder and Bluestein (2014).

What does a V_R observation represent?

The V_R estimate at a given range gate represents the reflectivity-weighted average velocity of all scatterers within a radar resolution volume during a given integration period (i.e., dwell time) towards or away from the radar. How does this relate to a 3 s, 10 m AGL wind speed standard?

- V_R estimate – Many pulsed Doppler weather radars use pulse-pair processing to calculate V_R, which often requires assumptions to be made about the shape of the power spectrum. The quality of the estimate is affected by factors such as the number and independence of samples used and the width of the power spectrum.
- Reflectivity-weighted average velocity – V_R estimates are typically biased towards the largest and/or most abundant scatterers being sampled. Typically, in high acceleration flows such as tornadoes, the peak velocity of the more massive objects is likely to be less than the peak velocity of the wind.
- Within a radar resolution volume – The size of the volume illuminated by the antenna is affected by the distance from the radar, the transmitted pulse width, and the antenna's radiation pattern. An antenna with a 3 dB beamwidth of 1º has a cross-sectional width of ~87 m, ~260 m, and ~525 m at 5, 15, and 30 km ranges, respectively. It's highly likely that the peak velocity of scatterers being sampled exceeds the mean velocity owing to spatial averaging. In addition, owing to beam broadening, partial beam blockage, and potential multipath scattering, the illuminated radar volume is likely to be quite complex for elevation angles near 0º, making it extremely difficult to sample near the ground.
- During a given integration period – the data that are used to calculate commonly-used radar quantities at each range gate are typically collected very quickly (i.e., dwell time per radial of ~0.005-0.05 s), so the calculated V_R data are nearly instantaneous velocities.
- Towards or away from the radar – Modeling and theory suggest that, within some tornadoes, the vertical component of the velocity may be similar to (or even exceed) the horizontal component. As such, minor deviations of elevation angle from true horizontal will result in an increasing contribution to the measured V_R from the vertical velocity.

	RaXPol
Wavelength	~3.1 cm (9.73 GHz +/- 20 MHz)
Transmit Power	Peak: 20,000 W Average: 200 W
Polarization	Simultaneous linear H and V
Range Resolution	15 – 150 m
Range Gate Spacing	7.5 – 75 m
Antenna Diameter	2.4 m
3 dB Beamwidth	1.0 deg.
Max. Antenna Scanning Rate	Azimuth: ~180 deg. s^{-1} Elevation: ~24 deg. s^{-1}

Table 1. Selected characteristics of the radar system used in this project.

31 May 2013

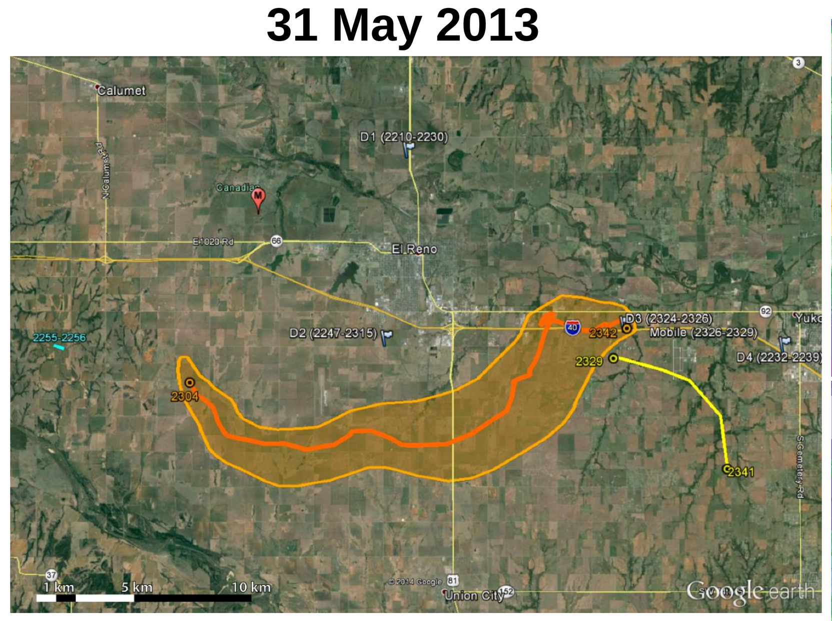


Fig. 1. A map of the RaXPol deployments near El Reno, Oklahoma, on 31 May 2013. The orange swath marks the track of the main "El Reno" tornado; the yellow curve marks an anticyclonic tornado track. A brief, weak tornado occurred before the primary cyclonic tornado began and is marked in light blue.

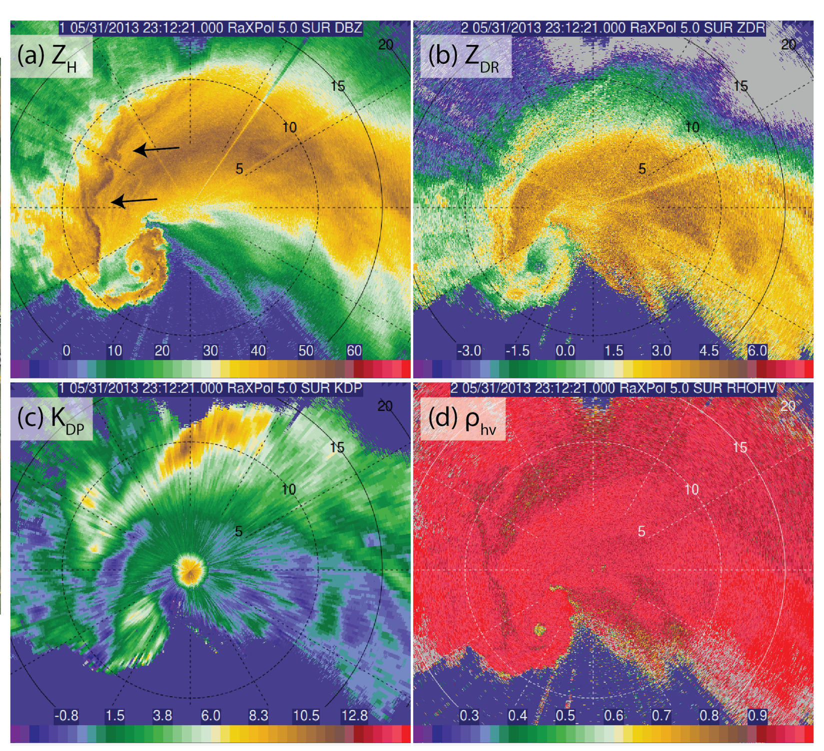


Fig. 2. RaXPol data from the second deployment location in southwestern El Reno as a tornadic supercell approached.

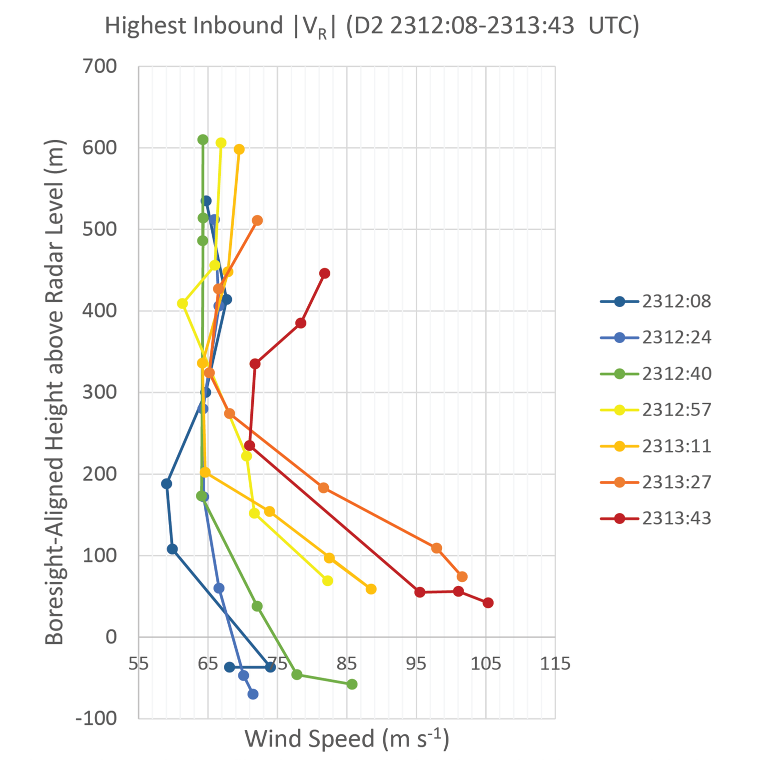


Fig. 3. The vertical profile of maximum $|V_R|$ at the end of the second deployment.

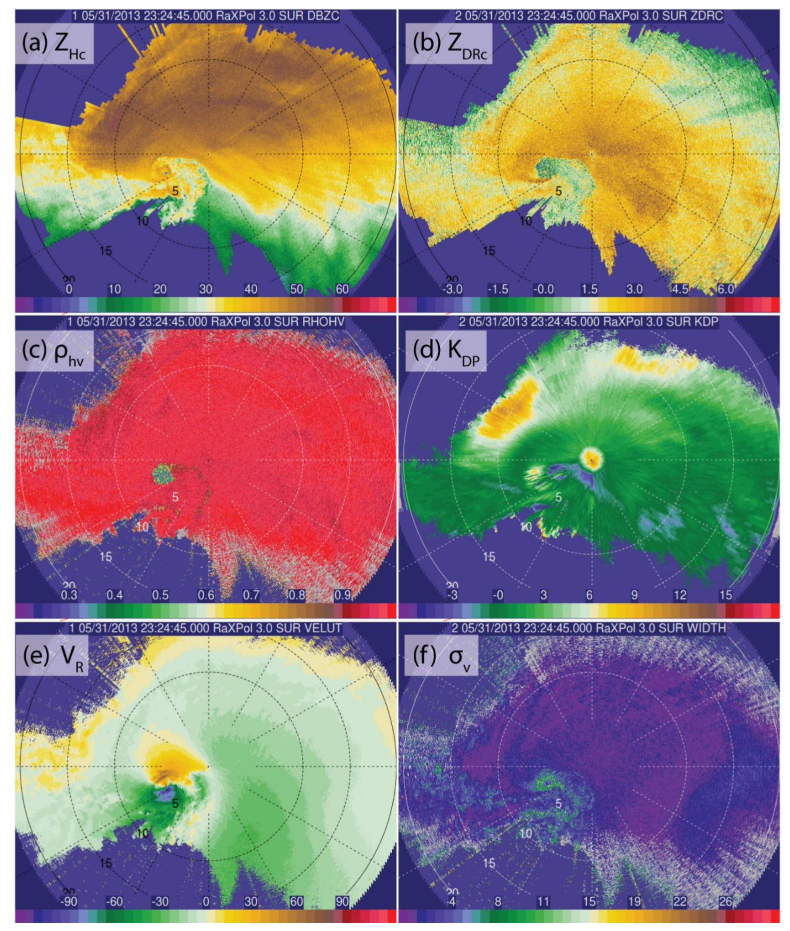


Fig. 5. A "zoomed out" view of the supercell near the start of the third deployment. Estimated attenuation by rain has been corrected for in (a) and (b).

Fig. 6. Photographs from (a) near the third deployment location, (b) the field in which RaXPol sampled V_R of at least 135 m s^{-1}, and (c) <1 m wide, helical swaths of matted vegetation in the same field. Photographs courtesy J. Snyder.

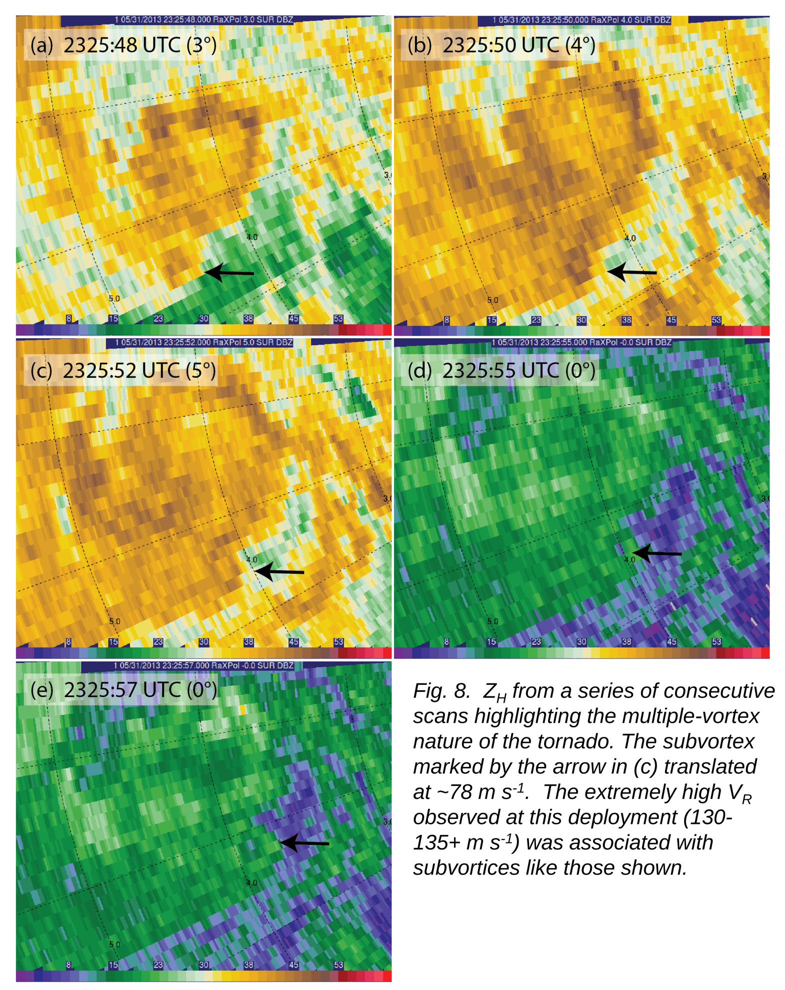


Fig. 8. Z_H from a series of consecutive scans highlighting the multiple-vortex nature of the tornado. The subvortex marked by the arrow in (c) translated at ~78 m s^{-1}. The extremely high V_R observed at this deployment (130-135+ m s^{-1}) was associated with subvortices like those shown.

Fig. 4. Photographs of the extremely large tornado in El Reno, Oklahoma, from RaXPol's third deployment location. The red circles in (a)-(b) mark the approximate size of the 3 dB beamwidth at the range of the tornado (3-5 km), and the white arrow in (c) points to RaXPol. (Photographs (a)-(c) courtesy of J. Snyder, H. Bluestein, and G. Rhoden, respectively).

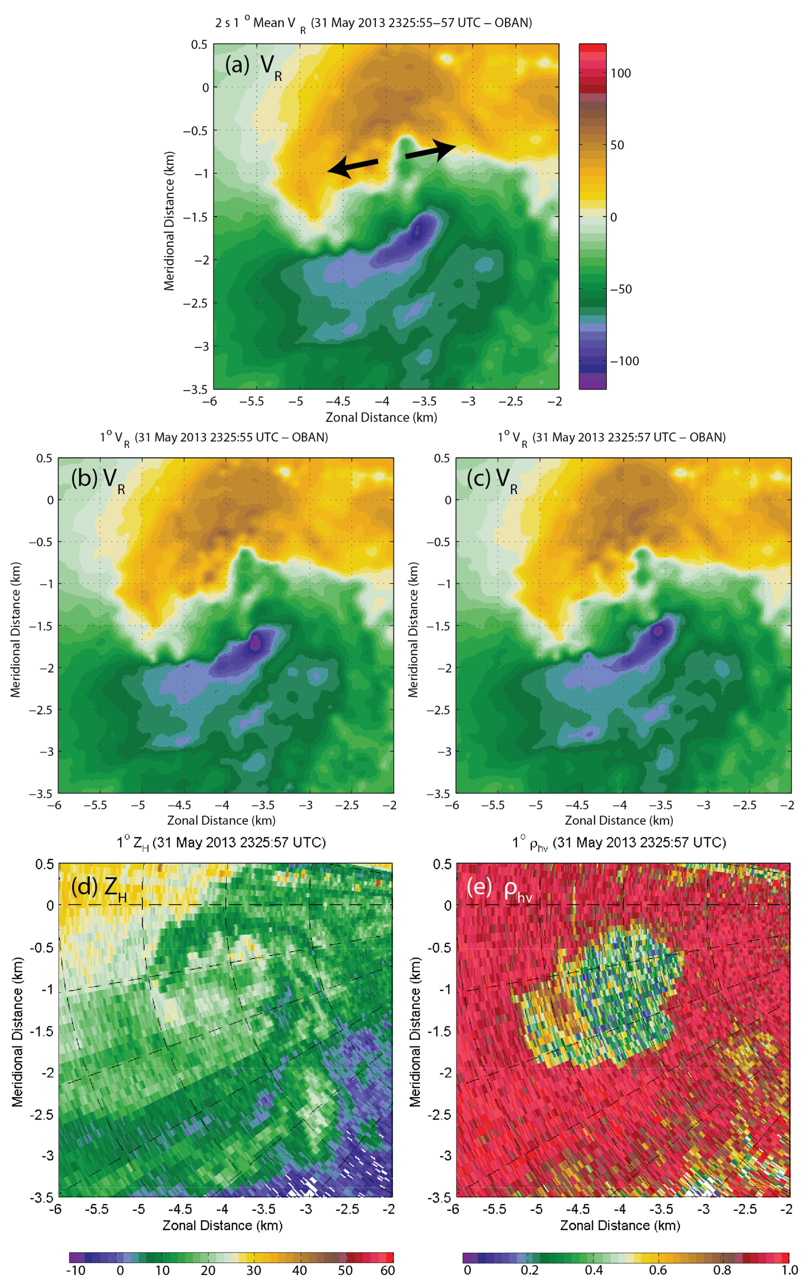


Fig. 7. (Left) RaXPol is currently configured to scan the lowest elevation angle of a volume scan twice, which means that the 0.0º elevation angle was scanned at a 2 s interval at every ~16 s during the latter part of the second and during the entire third deployment. As a result, we can average the two scans to estimate a 2-s average V_R, which reduces one of the primary sources of uncertainty when relating radar observations to the EF Scale. In this case, peak inbound V_R from two consecutive scans (b) and (c) is 119.5 and 116.4 m s^{-1}; the peak 2-s averaged V_R is 109.3 m s^{-1}.

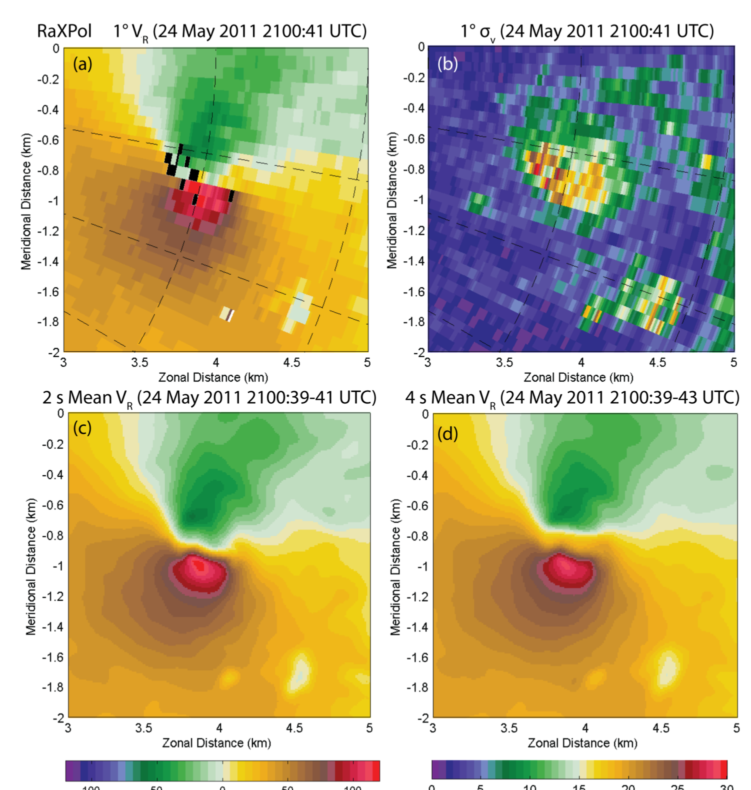


Fig. 9. On 24 May 2011, a violent tornado near El Reno, OK, passed ~2.5 km southeast of RaXPol. The scanning strategy at the times shown above consisted of 2 s PPIs at 1.0º elevation angle, which allows us to estimate the 2 s and 4 s average V_R. In this case, peak V_R in (a) is 132.1 m s^{-1}, peak V_R in the objectively analyzed data at this time (not shown) is 129.4 m s^{-1}; the peak in the (c) 2 s and (d) 4 s mean V_R is 118.4 m s^{-1} and 110.8 m s^{-1}, respectively.

Differential Velocity

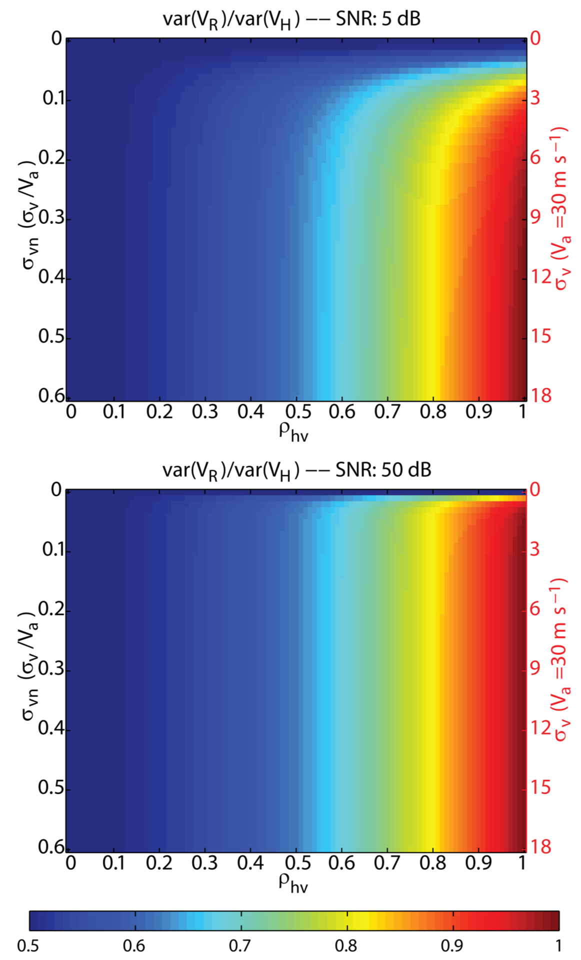


Fig. 10. Where ρ_{hv} ~1.0, V_V and V_H should be very similar since the signals in each channel are highly correlated. In the debris field of a tornado, however, ρ_{hv} tends to be markedly reduced. In such places, the combination of V_V and V_H (or the combination of the autocorrelation functions from H and V) to produce a "polarimetric" V_R estimate reduces the variance of the velocity estimate. Consequently, polarimetric radars should produce higher-quality V_R estimates in the presence of debris when compared to single-polarization radars. See Melnikov (2004) for details.

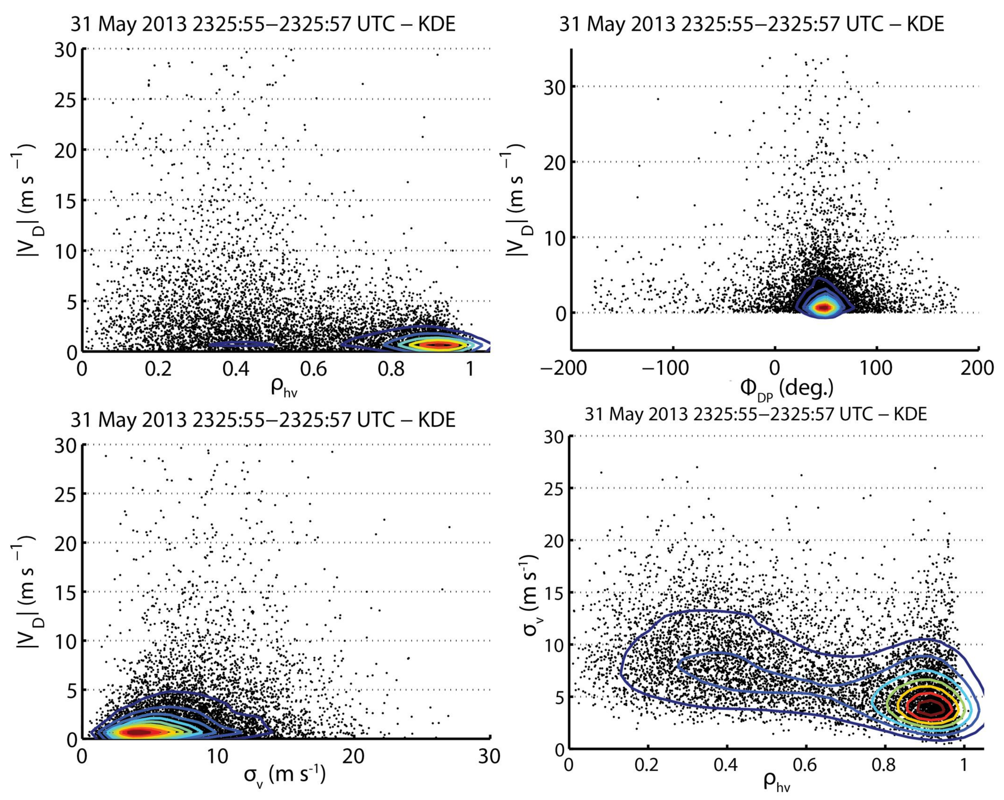
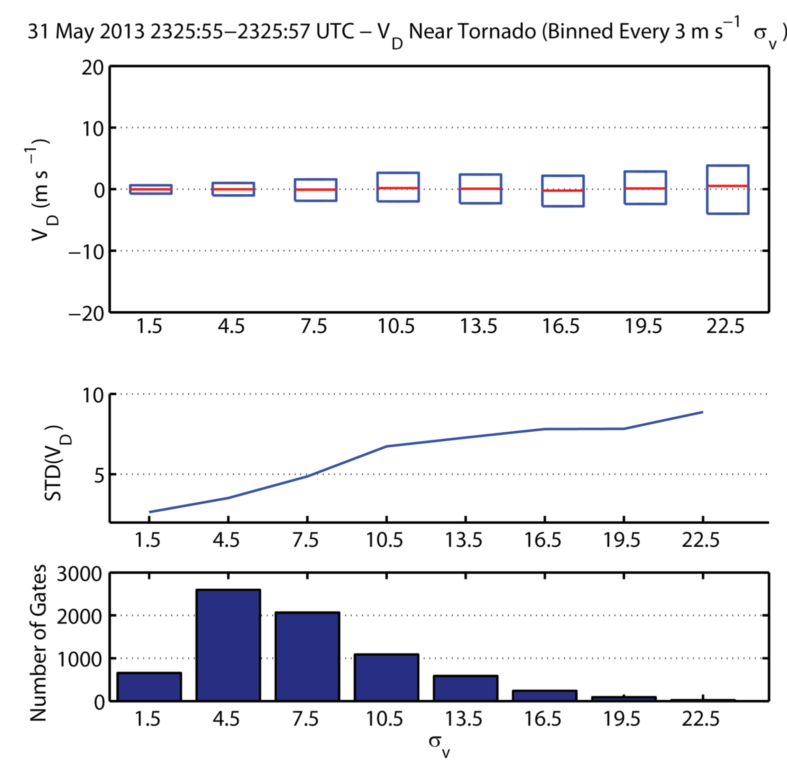
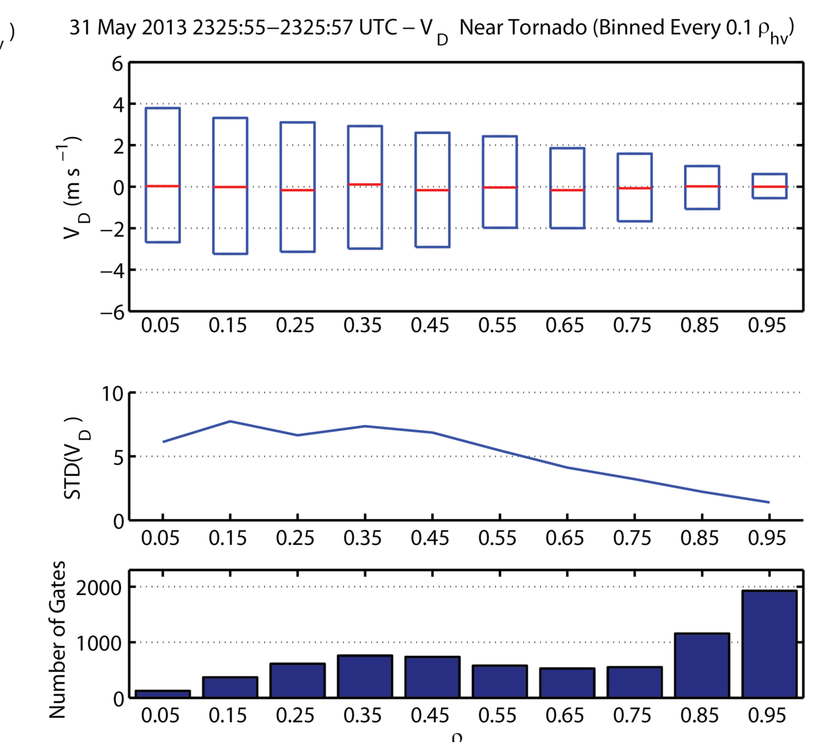


Fig. 11. Scatterplots and kernel density estimates (contoured) of the magnitude of differential velocity (V_D) for gates within and immediately surrounding the tornado debris field in two 0.0º elevation angle scans from the third deployment on 31 May 2013.

Fig. 12. (Below left) Median and ranges (10th-90th percentile) of V_D, standard deviation of V_D, and the number of data points for all gates near the tornado on two 0.0º elevation angle scans on 31 May 2013 as a function of spectrum width binned every 3 m s^{-1}.

Fig. 13. (Below right) As in Fig. 12, but as a function of ρ_{hv} binned every 0.1.





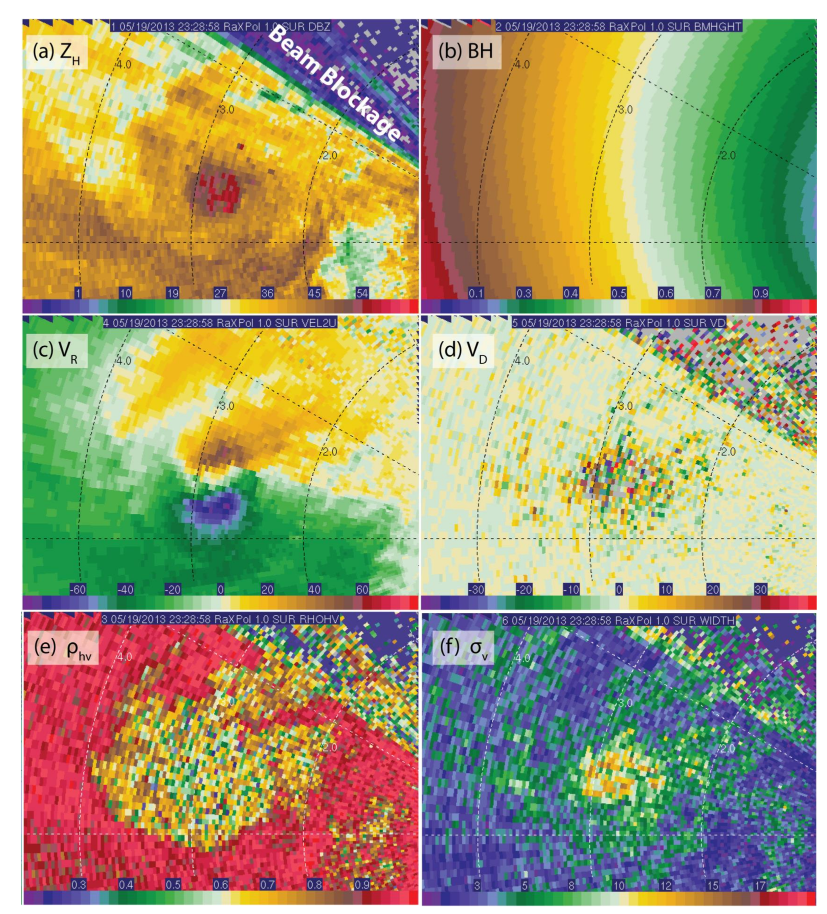


Fig. 14. RaXPol data from the evening of 19 May 2013 sampling a violent tornado centered ~2.8 km WNW of the radar. "BH" in (b) represents approximate boresight-aligned beam height above radar level after accounting for non-zero pitch and roll.

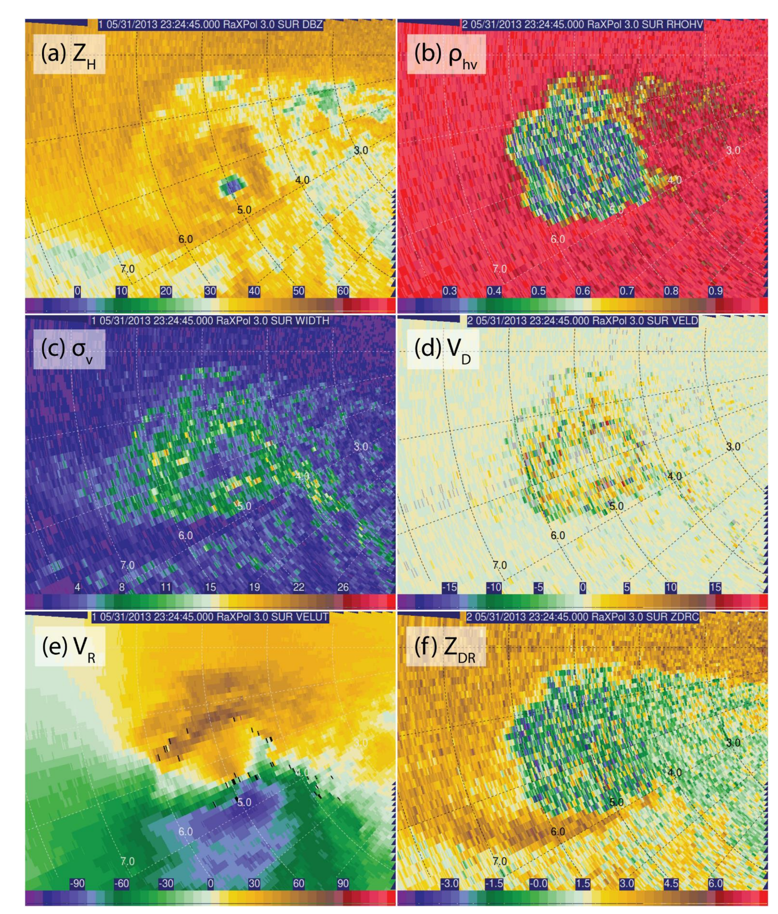


Fig. 15. RaXPol data from the evening of 31 May 2013 sampling a violent tornado SW of the radar.

Acknowledgments

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