POLARIMETRIC RADAR OBSERVATION OF A TORNADO AT C-BAND

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1. Introduction

From 25-27 October 2010, a historic mid-latitude cyclone deepened explosively as it propagated across the upper Midwest. According to Storm Data, this cyclone was responsible for 572 wind damage reports and 71 tornadoes from 25/1200 UTC to 28/1200 UTC. Of the 71 tornadoes, 12 of these occurred across the northern half of Indiana between roughly 1333 UTC and 1504 UTC in association with a strongly-forced quasi-linear convective system (QLCS). None of these tornadoes were rated higher than EF1, although EF2 tornadoes did occur as close-by as northeastern Illinois and northwestern Ohio.

One particular EF1 tornado touched down in the town of Wanatah in southwestern LaPorte County, Indiana, at around 1344 UTC. This tornado, hereby known as "the Wanatah tornado," was on the ground for approximately 3.04 km, had a maximum path width of approximately 135 m. The maximum winds, estimated based off of the damage, were approximately 40 ms^{-1}. The tornado destroyed several machinery buildings and damaged a couple residences on the east side of town.

The Wanatah tornado occurred approximately 15 km east-southeast of the campus of Valparaiso University, located in Valparaiso, Indiana. The campus is home to a state-of-the-art, polarimetric C-band radar. This radar captured clear signatures of the Wanatah tornado the morning of 26 October 2010.

Tornadic debris signatures observed by dual-polarization radars at S, C, and X-band, have been reported in previous studies: Ryzhkov et al., 2005, Bluestein et al., 2007, Kumjian and Ryzhkov, 2008, and Palmer et al., 2011. Debris particles typically have larger sizes, irregular nonspherical shapes, and random orientation. These characteristics result in a significant lower ρ_{hv} than what is usual for hydrometeors, Z_{dr} around 0 dB and high reflectivity (Ryzhkov et al., 2005). However, if a tornado is wrapped in rain, Z_{dr} may substantially increase, while ρ_{hv} remains low. Therefore, ρ_{hv} is considered the most powerful variable in the detection of tornadoes (Kumjian and Ryzhkov 2008).

This paper describes the meteorological setup of the system that produced the tornado in section 2, the VU C-band radar characteristics in section 3, and the polarimetric tornadic signatures in section 4.

2. Synoptic and Mesoscale Setup

The Wanatah tornado was a product of a massive

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bomb cyclone that dominated much of the continental United States in late October 2010. At 1200 UTC on 26 October, the surface low pressure was located over central Minnesota, with a minimum pressure of approximately 967 hPa. The cyclone would continue undergoing explosive cyclogenesis through the rest of the morning and afternoon, reaching an absolute minimum value of 955 hPa. Instability was rather unspectacular in the warm sector, owing to rather warm upper-level temperatures over the area. Mid-level lapse rates generally ranged from 5.2-5.8 $°Ckm^{-1}$, with MLCAPE on the Detroit, Michigan (DTX) and Wilmington, Ohio (ILN) soundings of 1066 Jkg^{-1} and 1559 Jkg^{-1}, respectively. Both soundings featured stable surface-based parcels, however, with SBCAPE values under 50 Jkg^{-1}. The QLCS that produced the tornado outbreak across the Midwest formed immediately ahead of a powerful, fast-moving cold front associated with the cyclone.

3. The VU C-band Polarimetric Radar

The Valparaiso University C-band polarimetric radar was constructed in 2007 by Enterprise Electronics Corporation based out of Enterprise, Alabama. The simultaneous dual-polarization radar pulses at a wavelength of 0.053 m with 1 MW of power. The first elevation tilt is 0.49°. On 26 October 2010, the radar was operating with a pulse repetition frequency (PRF) of 1014 s^{-1}, a Nyquist velocity of 26.1 knots, and a maximum range of 300.0 km.

4. Polarimetric observations

4.1 Cross-correlation Coefficient (ρ_{hv})

The 1346 UTC volume scan from the Valparaiso radar (figure 1.a and 2.a) showed a fairly clear tornadic signature in cross-correlation coefficient (ρ_{hv}) moment of the scan. The minimum in ρ_{hv} observed in association with the part of the line encompassing the Wanatah tornado event was 0.48 and had vertical consistency in the volume scan (Figure 3. a). This value of ρ_{hv} was consistent with the 0.8 or lower values associated with past tornadic signatures (Ryzhkov et al., 2005). Therefore, the conclusion can be drawn, given the time and space considerations of the 1346 UTC volume scan, that the minimum in ρ_{hv} is likely associated with the Wanatah tornado vortex.

4.2 Differential Reflectivity (Z_{dr})

A differential reflectivity (Z_{dr}) of near <0.5 dB has been found to be associated with tornadic signatures in polarimetric analysis of other tornado events (Ryzhkov et al., 2005) In the Wanatah case, however, there is a maximum in Z_{dr} around the location of the tornado (figures 1.b, 2.b and 3.b). This spike in differential reflectivity near the tornado vortex may be explained by the presence of large raindrops mixed with debris near the vortex, as was suggested in previous studies (Kumjian and Ryzhkov, 2008). Moreover, the scatterplot of Z_{dr} vs ρ_{hv} (figure 4.c) shows that the lowest values of ρ_{hv} (below 0.8) are associated with Z_{dr} values ranging from slightly negative to close to 4dB. The hypothesis that raindrops are responsible for high Z_{dr} is further supported by the radar reflectivity as discussed in section 4.3.

4.3 Reflectivity (Z)

Reflectivity values close to the location of the tornado are very high, as seen in figures 1.c, 2.c and 3.c. However, the scatterplot of Z vs. ρ_{hv} (figure 4.b) shows that the lowest ρ_{hv} values have reflectivities between 10 and 40 dBZ. Hence, the gates that have high Z are not the same having low ρ_{hv}, although they are very close.

The reflectivity in the tornado is well below the >45 dBz often associated with tornado debris signatures (Ryzhkov et al., 2005). This weakness in reflectivity is likely due to the small size of the particles elevated by the tornado vortex because of its rather weak nature.

The high reflectivity seen in the first figures may be a consequence of the presence of rain surrounding the tornado, as was already suggested in the previous section. Figure 4.a further supports this assumption, since higher Z is linked to high Z_{dr}, as expected for rain.

5.Summary and Discussion

A tornado of weak intensity passed in close proximity to the Valparaiso University C-band polarimetric Doppler radar on the morning of 26 October 2010. The radar collected a good sample of the tornado on one full volume scan. The scan revealed a classic ρ_{hv} signature associated with past tornado events detected on polarimetric radar. However, the traditional high Z tornadic signal was not present in the 26 October case probably due to the small size of debris particles as a result of the rather weak nature of the tornado. The low Z_{dr} signature usually found in tornadoes was not observed with the radar likely due to the heavy rain occurring near the vortex.

Acknowledgements:

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6. References

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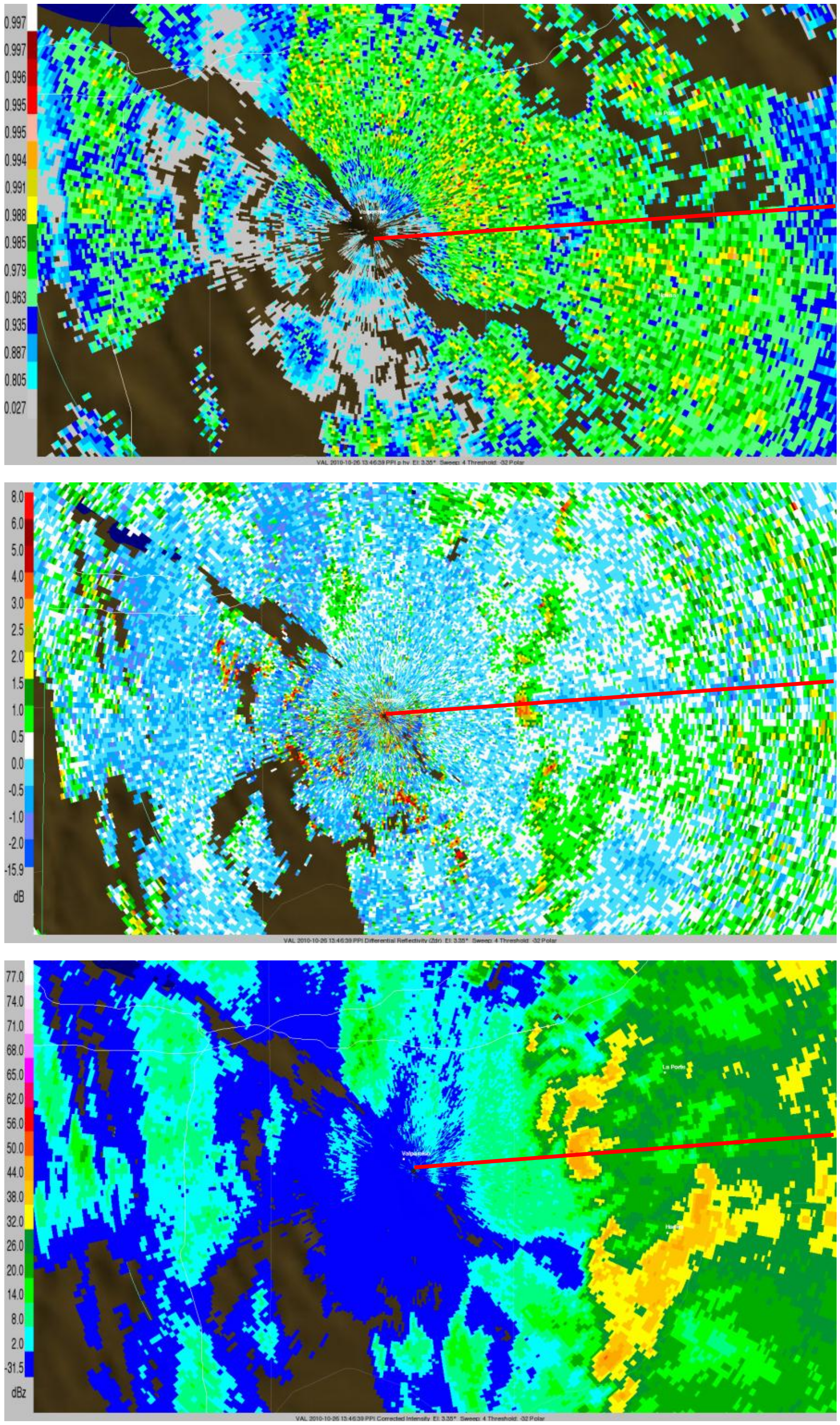
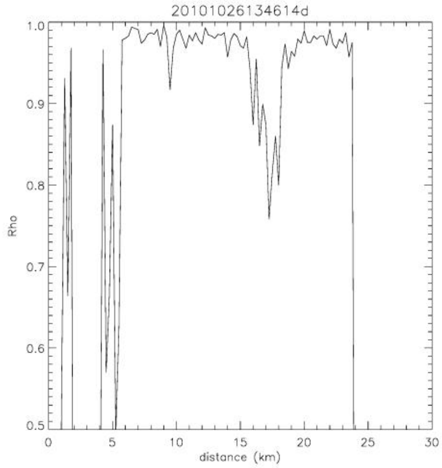


a)

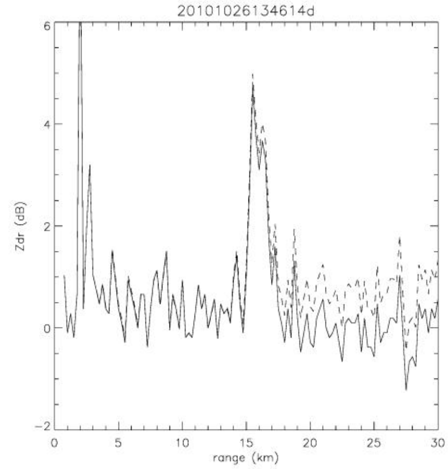
b)

c)

Figure 1. ppi at 3.35 ° of elevation at 1346 UTC showing a) ρ_{hv} , b) Z_{dr}, and c) Z.



a)



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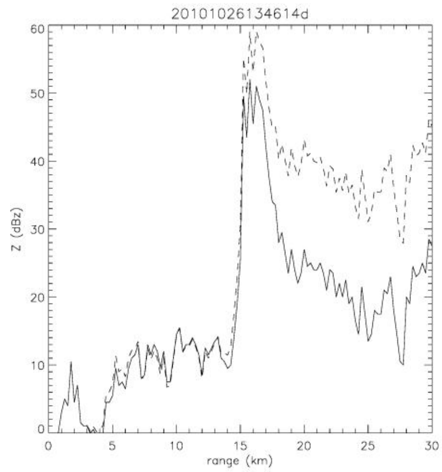
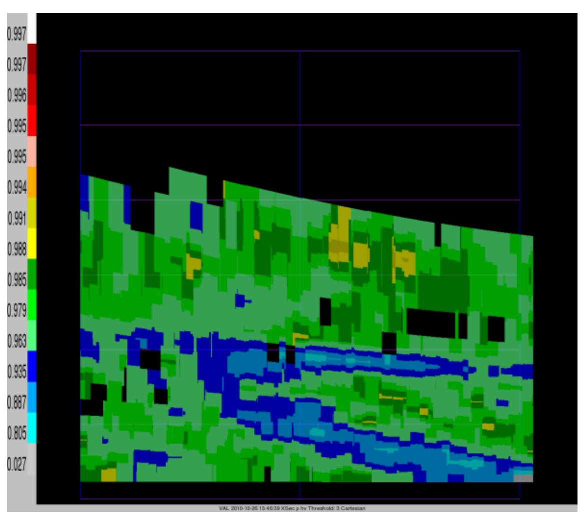


c)

Figure 2. Radial across the tornado location (red line in figure 1.) for a) ρ_{hv}, b) Zdr, and c) Z. The dashed line in b) and b) correspond to Z and Z_{dr} after attenuation and differential attenuation correction.



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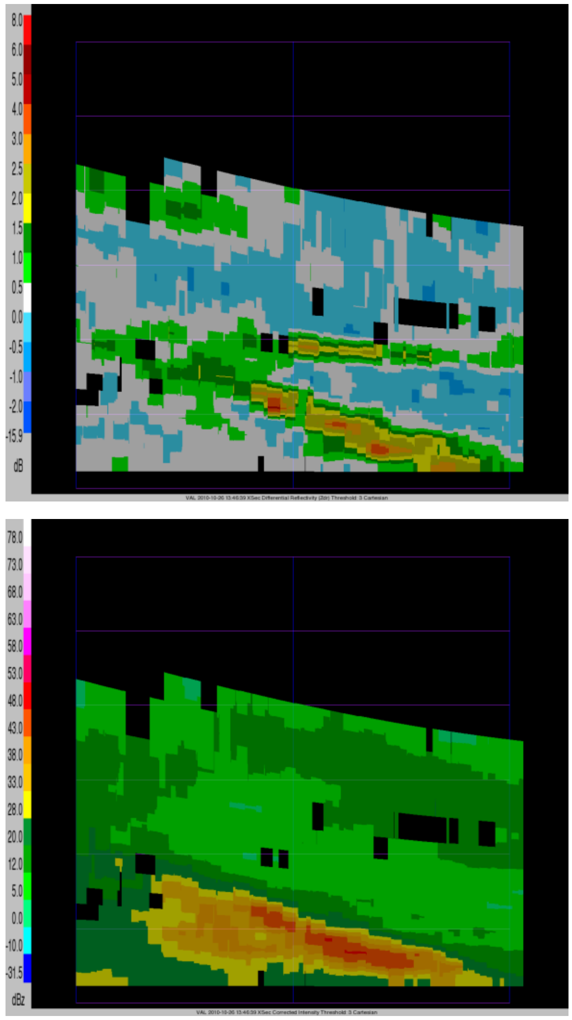

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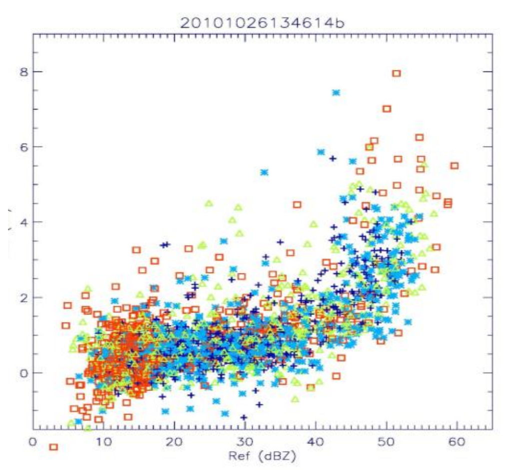
Figure 3. Cross-section from northeast to southwest across the tornado. a) ρ_{hv}, b) Zdr, and c) Z.



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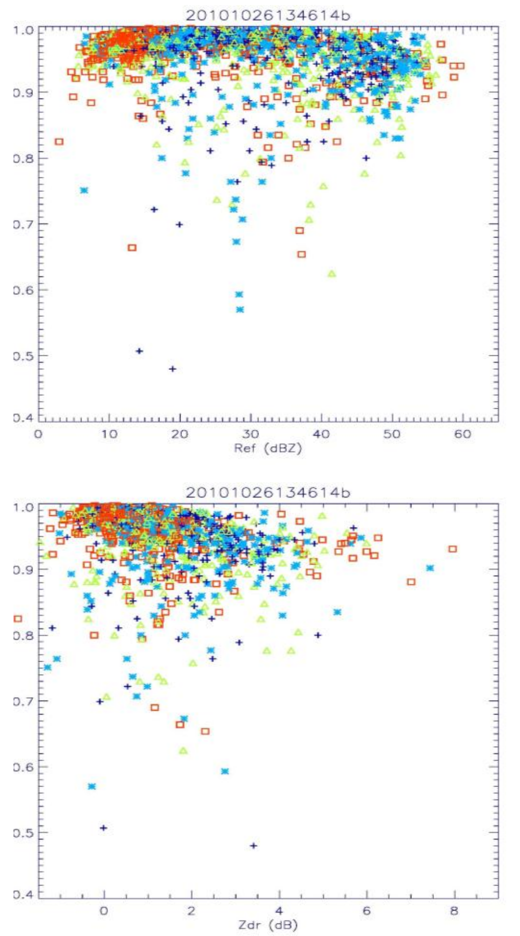

b)

c)

Figure 4. Scatterplots comparing the polarimetric moments: a) Z vs Z_{dr}, b) Z vs ρ_{hv}, c) Zdr vs ρ_{hv} . The points in the scatterplots are within 12 to 20 km range between azimuths 80° and 100°, in the 4 lowest tilts (0.5°, 1.5°, 2.25°, 3.35°). The colors and symbols represent different elevations: dark blue 'plus sign' = 0.5°, light blue asterisk = 1.5 °, green triangle = 2.25 ° and orange square = 3.35 °.