Examining the Effects of the Ground on the Radiation Pattern of a Parabolic Reflector at Very Low Elevation Angles

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Introduction and Motivation

- Remote sensing technology like radar can be an extremely effective tool for detecting and examining the characteristics of tornadoes
- An increasing number of radar observations have been collected near and within tornadoes
- Resolving a tornado's flow near the ground typically requires that a radar be very close to the tornado, significantly increasing the danger to radar and personnel
- To investigate the relationship between wind characteristics and damage that is produced by a tornado (e.g., as applied through the Enhanced Fujita Scale), it is important to know what scatterers are contributing most to the radar measurements at a given location and time. What does the radar beam look like at a given range, azimuth, and elevation? Does the radar beam "reflect" off the ground? How strong is the multipath scattering?
- In light of several recent events, it is worthwhile examining how the ground can affect the radiation pattern of a radar when scanning at very low elevation angles
- Radar beam interactions with the ground are likely to be a more common issue for mobile radars, which tend to be located closer to the ground than are fixed-site radars, and they occasionally collect data when the radar is not perfectly level.

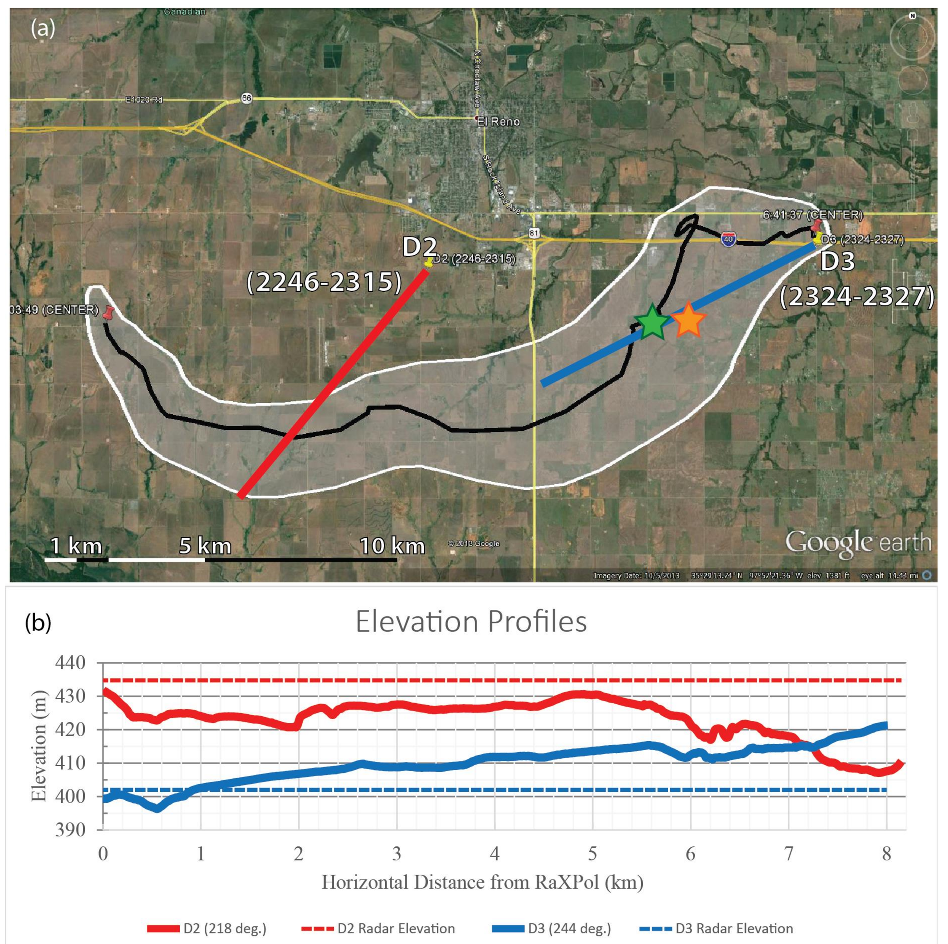


Fig. 1 (Right). RaXPol collected data near an intense tornado (marked in white; tornado center path marked in black) on 31 May 2013 in central Oklahoma (e.g., Wurman et al. 2014; Snyder and Bluestein 2014; Bluestein et al. 2015; Wakimoto et al. 2015). Despite collecting at 0º el. angle at a range of less than 5 km, it seems likely that the lowest 10 m AGL was not well sampled. Reasons for this include partial beam blockage, terrain variability (see elevation profiles), beam broadening, and unknown contributions from ground effects. At deployment #3 (D3), terrain rose to the southwest. What did the illuminated radar volume look like at low elevation angles?

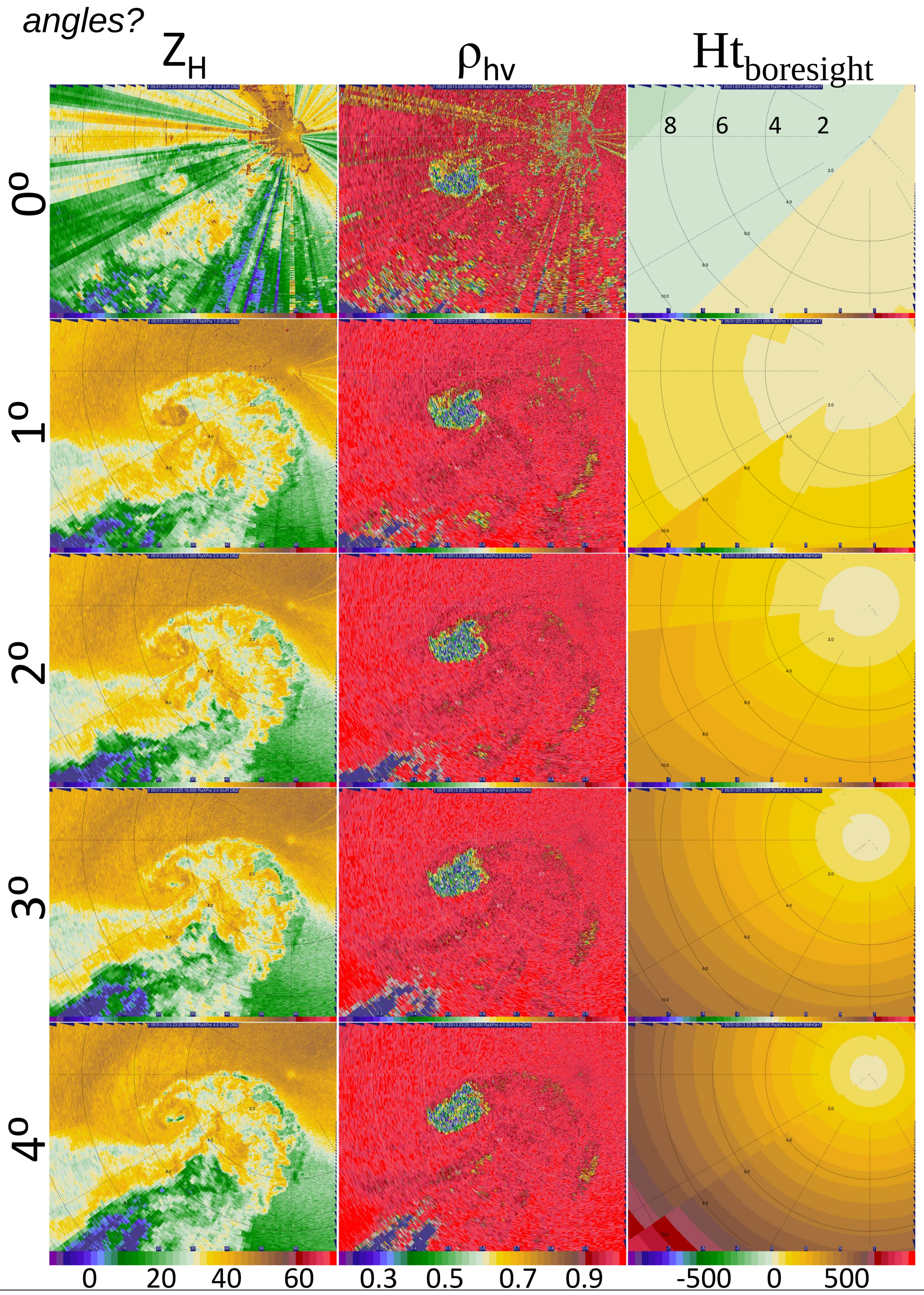


Fig. 2 (Left). Z_H (dBZ), ρ_{hv}, and the height of the beam centerline along antenna boresight ($Ht_{boresight}$) for one radar volume collected on 31 May 2013. Despite our best efforts, RaXPol had non-zero pitch and roll, and very strong wind gusts buffeted the radar truck. As a result, beam height above radar level (ARL) varied in azimuth. When the tornado was southwest of the radar, boresight-aligned theoretical beam height was < 0 m ARL. The ground elevation increased to the southwest, so the antenna pointed into the ground when scanning at 0º elevation angle. Despite that, the Z_H structure of the tornado at 0º elevation angle looks much more like that at 1º elevation angle than that at 2º-4º. Range rings are marked every 2 km.

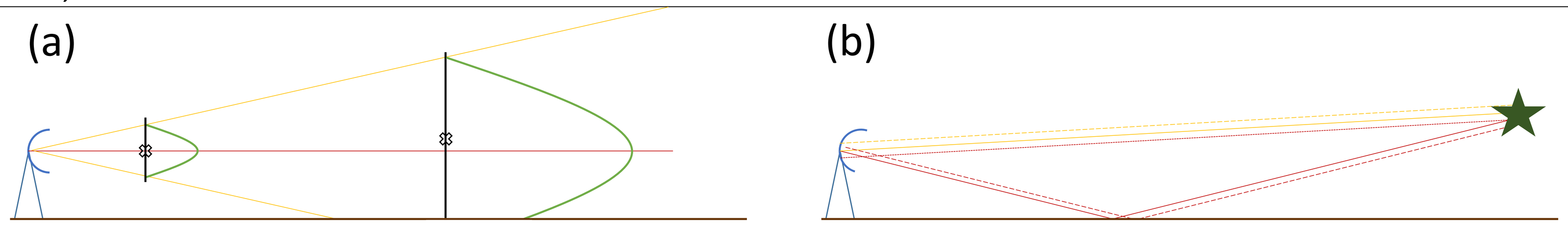


Fig. 3. A cartoon illustration of the scattering problem being investigated. (a) At an elevation angle of 0º and assuming horizontal ground, the beam boresight height (red line) will remain constant with range. The lower part of the beam (marked by the yellow line), owing to beam broadening, intercepts the ground. The net effect is an increase in the height of the level of mean electric field strength (marked by an "x") as the electric field strength at the bottom of the beam is reduced (green curve). (b) At an elevation angle < 0º, the beam centerline will interact with the ground. Some of the energy in the main lobe may scatter or "reflect" off the ground. A target (green star) may then scatter energy directly back to the radar (off centerline; dotted red line) or scatter energy back along the propagation path (dashed red line). Energy outside of the center of the beam (including side lobes; yellow line) may scatter back to the antenna as well (yellow dashed line). If most of the energy in the main lobe is "lost" as a result of intercepting the ground, these sidelobes may contribute appreciably to the total received signal.

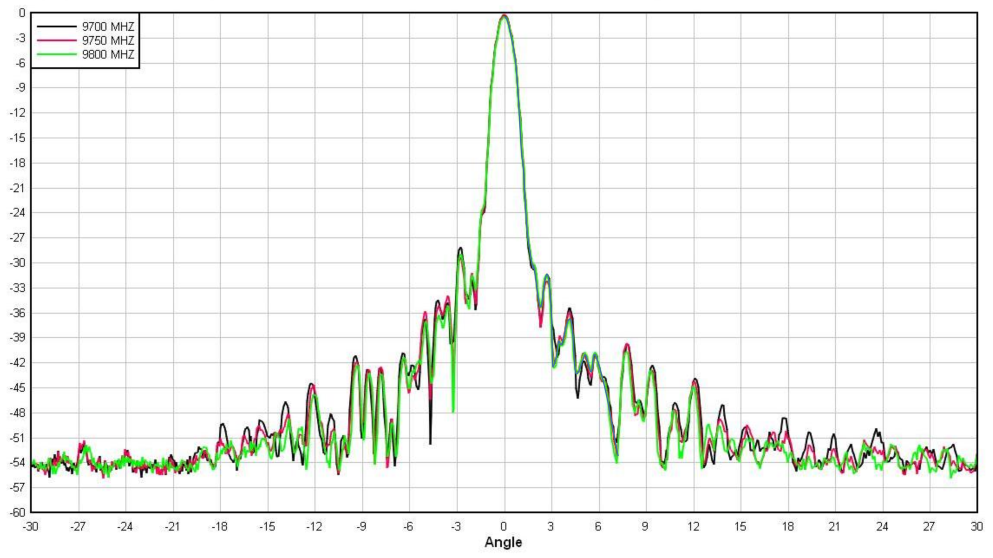
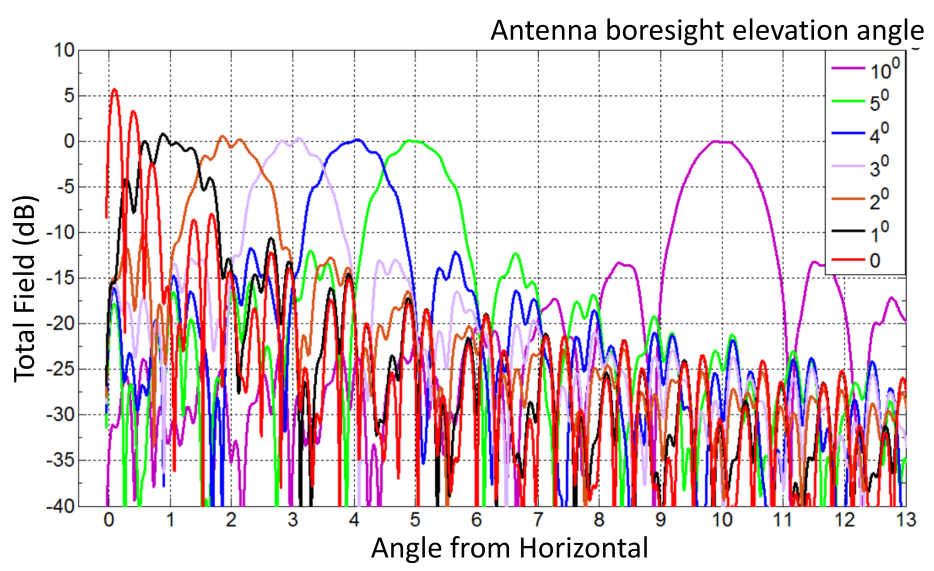


Fig. 4 (Left). Antenna manufacturer's test results of RaXPol's beam pattern in the horizontal channel at three frequencies within X band. The 1.8 m diameter parabolic antenna has a 3 dB beamwidth of ~1.0º.

EM Modeling

Fig. 5 (Right). Theoretical modeling resolutions were investigated by using image theory in order to evaluate the ground reflection effect on the radiation patterns of the reflector/antenna. The results indicate that the main lobe became more complex and sidelobe levels increased significant at the lowest elevation angles.



Solving very large electromagnetic radiation and scattering problem is not possible in the HFSS-FEM (Finite Element Method) solver. Therefore the HFSS Integral Equation (HFSS-IE) solver can be used to solve this problem. The HFSS-IE solver uses the Method of Moment (MoM) technique to solve for the currents on the surfaces of conducting objects in open regions. In applications such as the reflector antenna, HFSS 3-D designs of antennas can be linked as a radiation source in an HFSS-IE design using a data link. The source can be created in HFSS, and its fields are linked from that simulation into the target HFSS-IE design

A horn-fed reflector antenna system is simulated and analyzed using the Ansoft HFSS and HFSS-IE design environment. After designing the horn antenna (as a feeder) in Ansoft HFSS, the reflector antenna is designed in the HFSS-IE with excitation linking to Ansoft HFSS design.

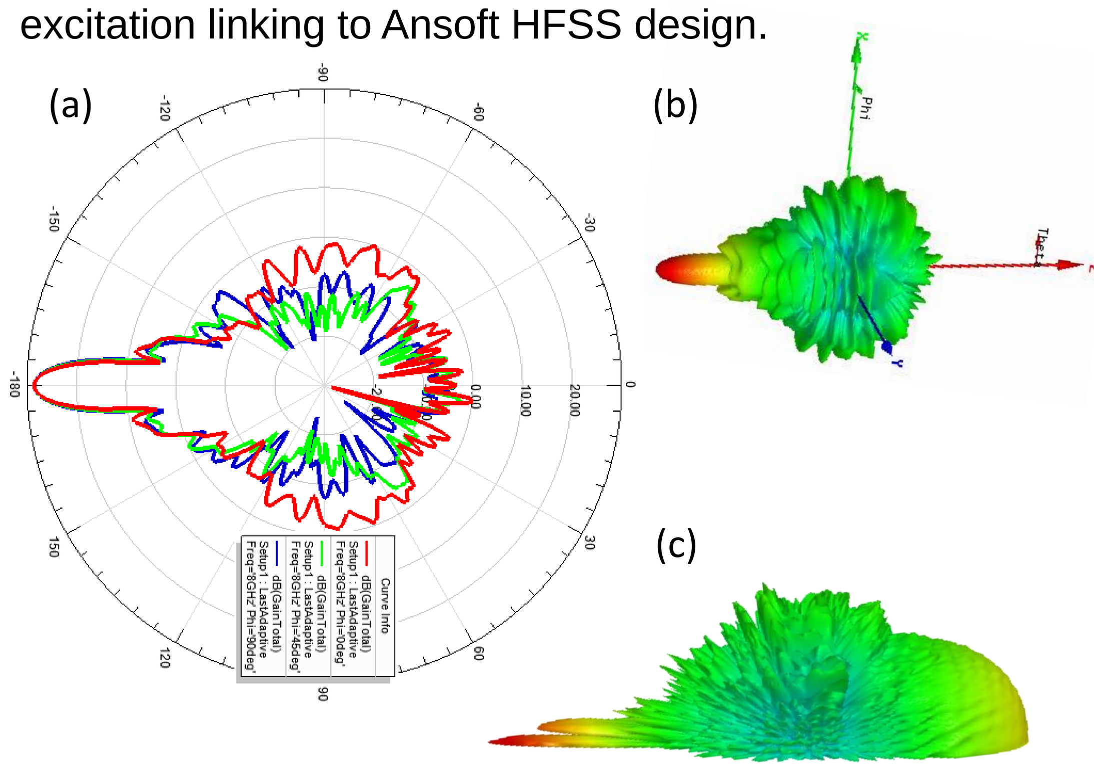
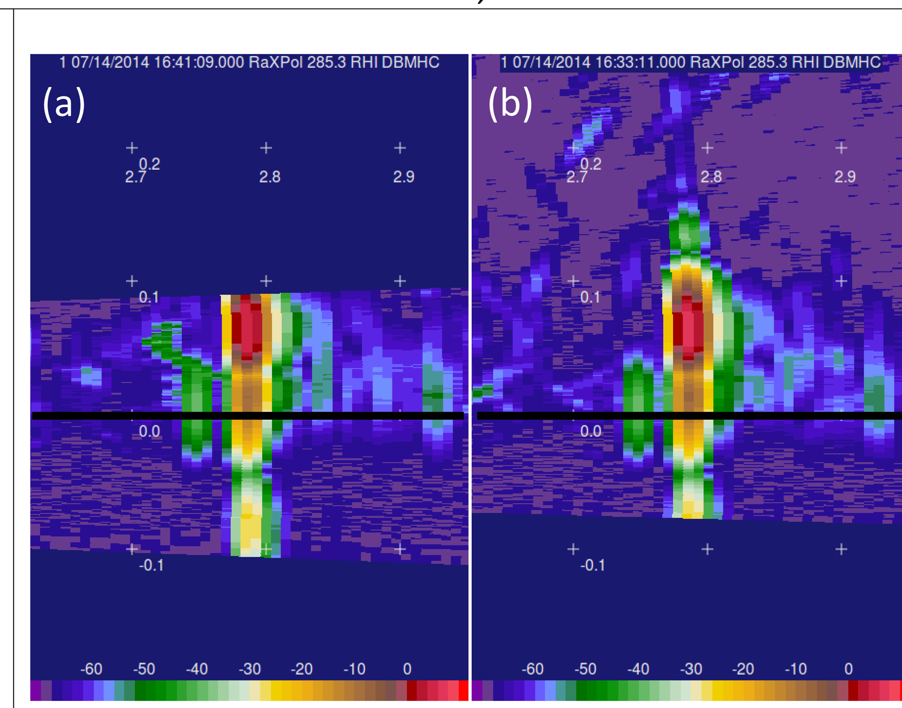


Fig. 6. The (a) 2-D and (b) 3-D radiation patterns of the modeled reflector/antenna. The infinite ground plane is included in (c) to investigate the ground plane effect (i.e., ground reflections). Because of the infinite ground plane assumption, the radiation pattern in the lower hemisphere is zero.

Tower Measurements



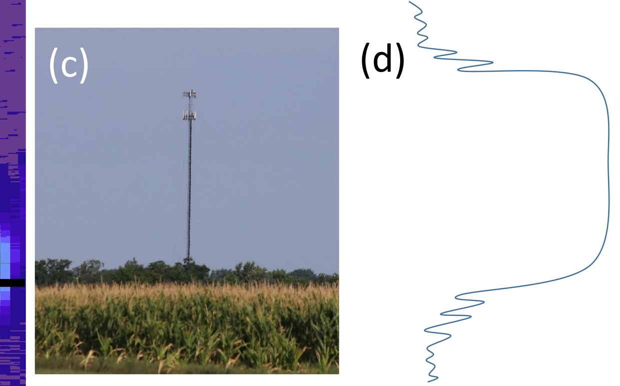


Fig. 7. (a)-(b) True RHI scans from RaXPol through an antenna tower similar to the one pictured on the right. Shown is received power (dBm) from the horizontal channel. Data were collected on 14 July 2014 in central Oklahoma. Tick marks are shown every 0.1 km. Range resolution and gate spacing was 15 m and 7.5 m, respectively. The horizontal black line marks the radar antenna height. (c) A photograph of one of the towers scanned. (d) An illustration showing what one may expect to see in the received power from scanning a tower.

Fig. 8 (Right). Received power (dBm) from scans similar to those shown in Fig. 7 valid at the range of a different antenna tower. Blue and red curves represent data from the horizontal and vertical channels, respectively. Note the local maximum near -75 m ARL is nearly 30 dB less than the main lobe, similar to the antenna's first sidelobe.

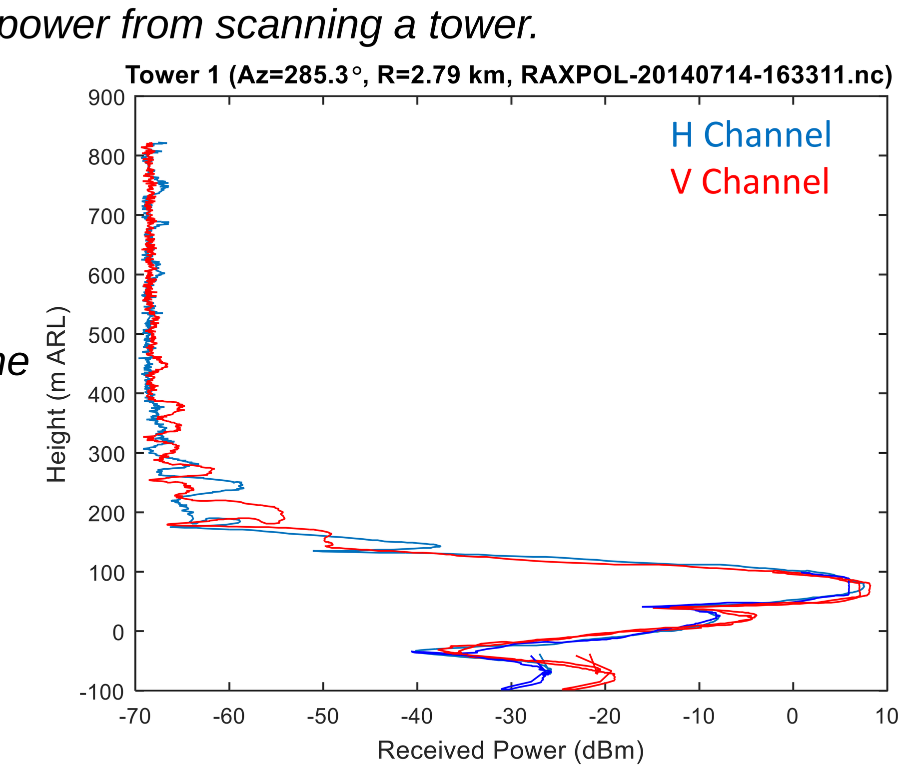
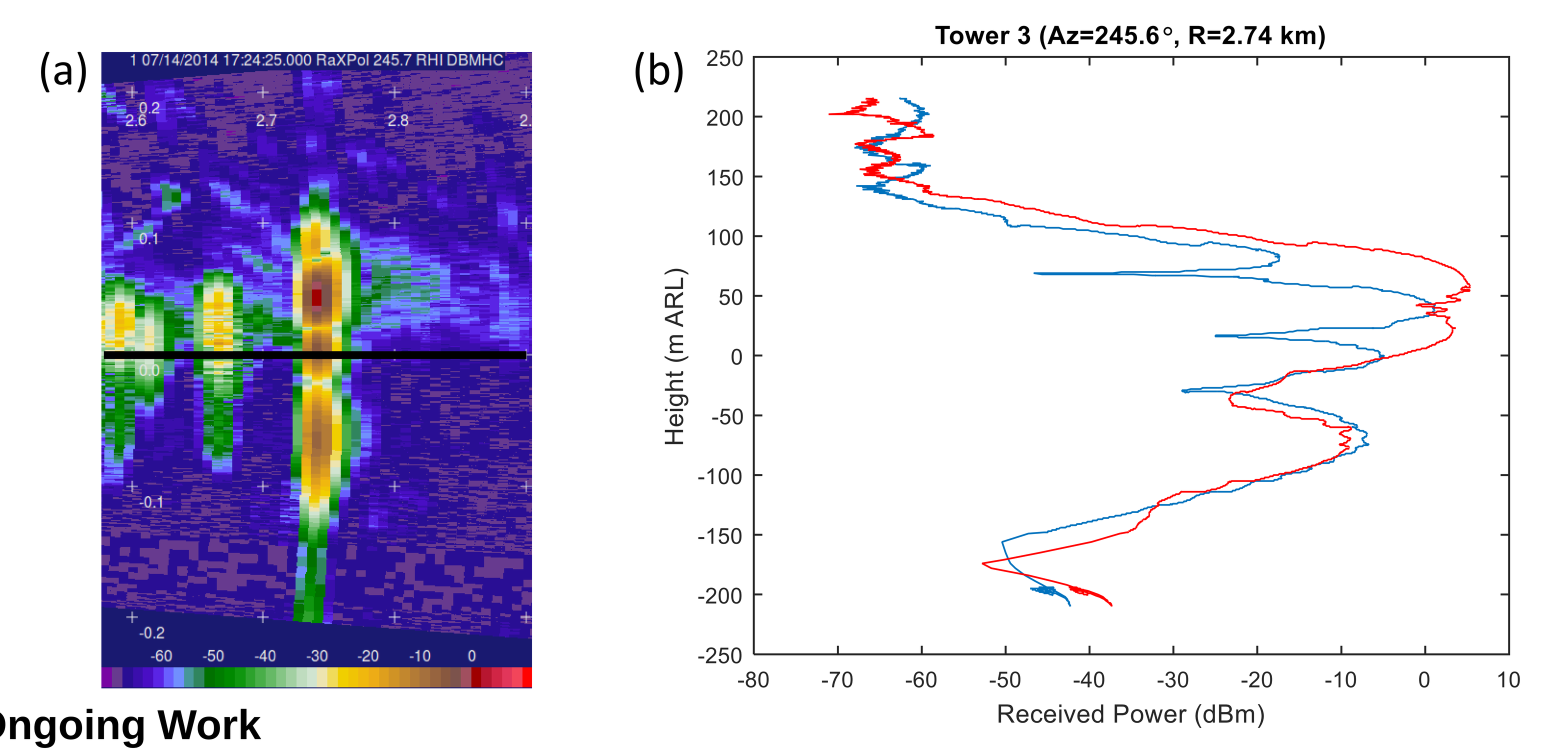


Fig. 9 (Below). (a) RHI from RaXPol through another antenna tower. Shown is received power (dBm). (b) Similar to Fig. 8 except valid for the tower sampled in (a). Note the much different H and V channel profiles. Elevation angles of 4.0º to -4.0º were scanned. The local peak in received power near -75 m ARL is much greater in magnitude than that of the first sidelobe of the antenna, indicating that energy from the main lobe is being scattered by the tower even when scanning at <0º elevation angle.



Ongoing Work

A more thorough and controlled collection of radar measurements from stationary, near-ground targets are being conducted and will be reported on in the future. In addition, we continue to investigate additional modeling studies of the radiation pattern at near-horizontal elevation angles. It is hoped that, through these experiments, we will be able to better quantify the representativeness of data collected at very low elevation angles relative to anticipated scatterer heights.

Acknowledgments

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