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Effects of Phased-Array Radar Beam Shapes on Velocity Signatures of Modeled Vortices: A Simulation Study

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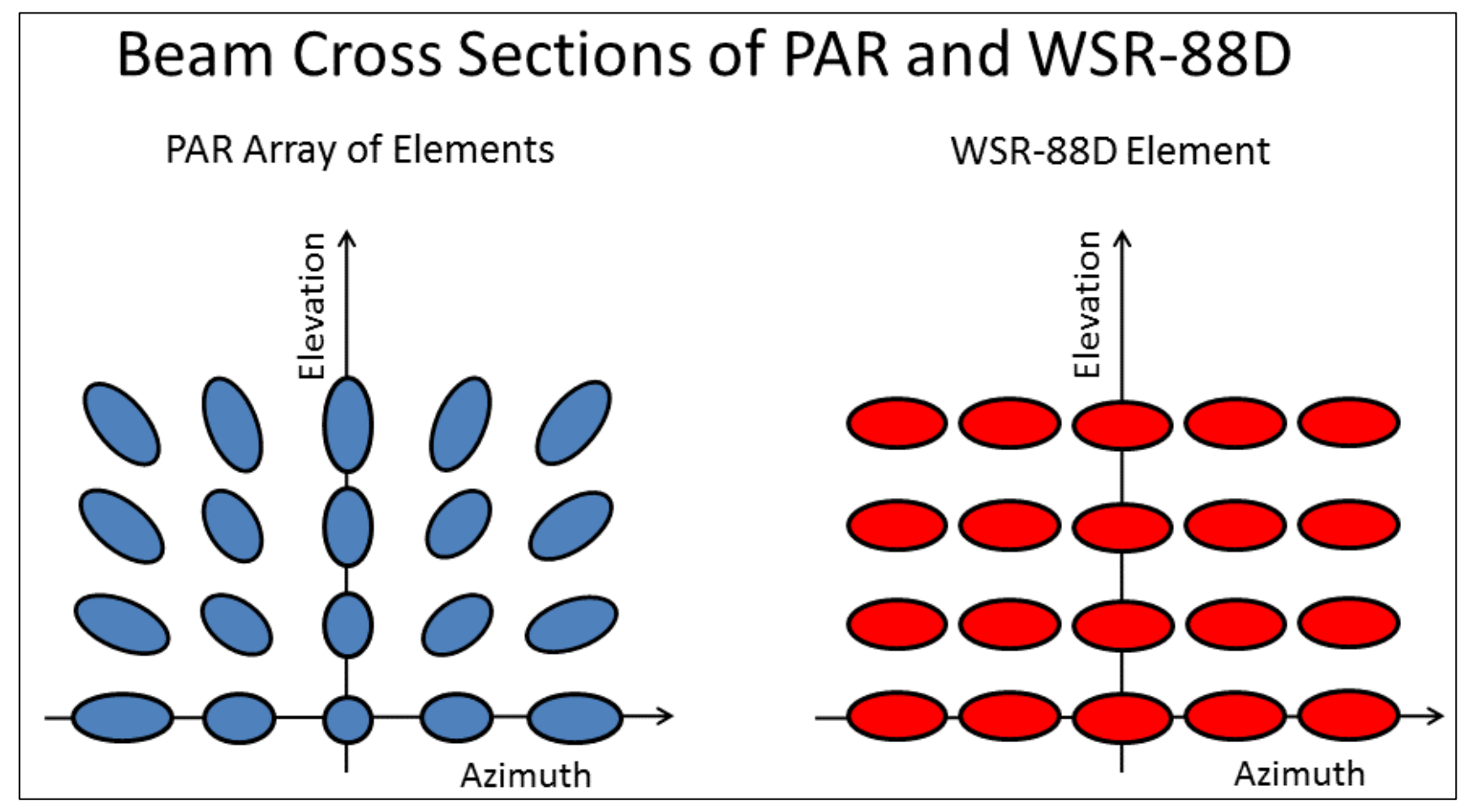
Background

- Brown and Wood (2012) presented a simulated phased array radar (PAR) that produced Doppler velocity signatures of various-sized analytical vortices (representing tornadoes and mesocyclones) across the full 90º-wide sector covered by a planar antenna face out to ranges of 240 km at lowest elevation angle.
- The authors scanned the virtual radar beam horizontally away from the principal plane at a given range from the PAR.
- The authors, however, did not scan the beam vertically away from the plane.
- Thus, we extended the Brown and Wood approach by investigating the effects of three-dimensional beam broadening on vortex detection and estimates of the simulated Doppler velocity signatures of vortices. The results were then compared to those produced by a simulated WSR-88D.

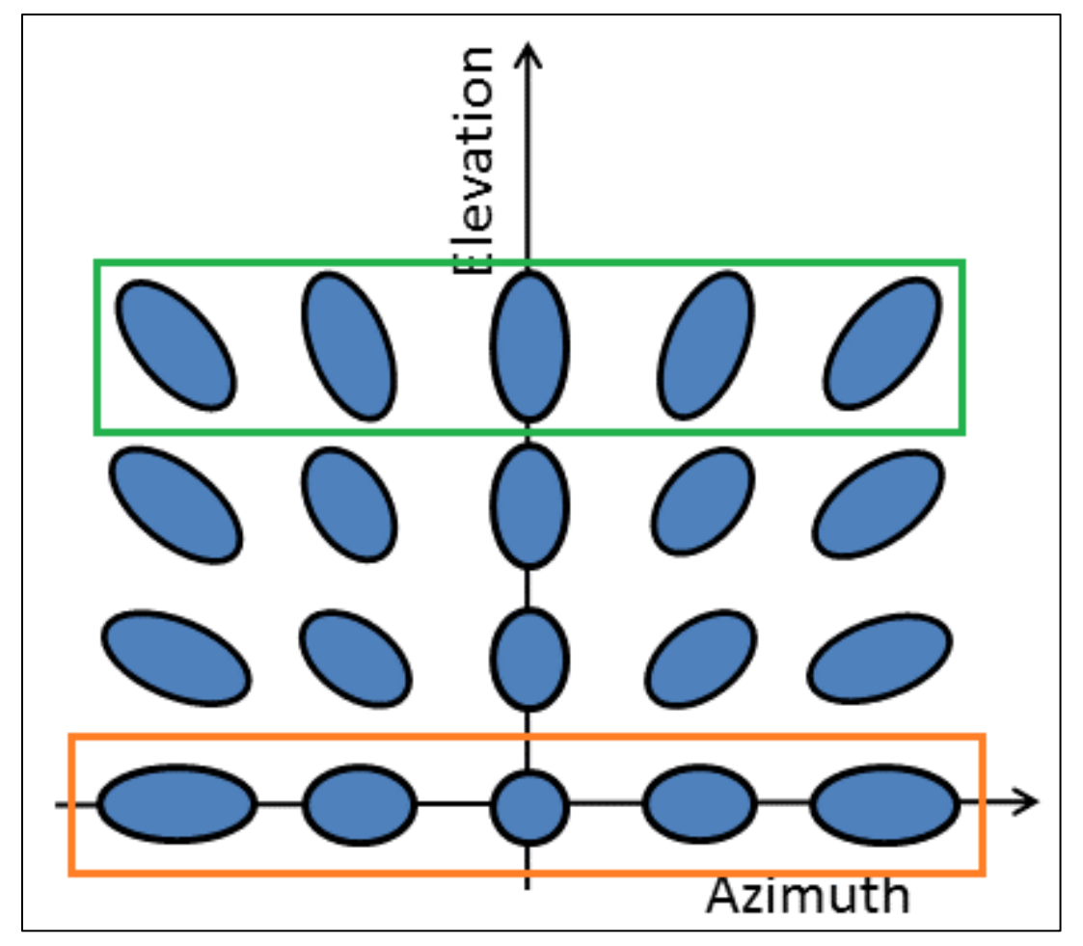
Approach

- The **figure on the left** shows that the **blue** beam varies as a function of azimuthal as well as elevation directions from a broadside circular beam at a given range from the virtual PAR radar.
- The **figure on the right** shows that when a virtual WSR-88D antenna scans azimuthally while it is collecting a sufficient number of samples to compute representative values of radar variables, the data are smoothed somewhat as if the horizontal width of the radar beam were wider than the transmitted beam. The **red** width of the hypothetically widened half-power beam is called the ***effective*** beamwidth (Doviak and Zrnić 1993).



The beam cross sections of PAR array of elements (left, ***blue****) and WSR-88D element (right,* ***red****) are shown. At left, the beamwidth and shape vary as a function of beam directions (elevation and azimuth). The circular beam shape, for example, becomes elliptical as we scan away from broadside. At right, the effective beamwidth varies only with increasing azimuths as the WSR-88D antenna scans azimuthally. In this case, the elliptical beam shape remains unchanged.*

- For narrow beams, beamwidth (BW) varies in the azimuthal (vertical) direction according to BW = BW_o / cos θ, where BW_o = 1.5º is the broadside beamwidth and θ is the azimuth (elevation) angle relative to the broadside direction.
- We computed an azimuth spacing ΔAZ by dividing BW by 2 (i.e., ΔAZ = BW/2), and an elevation spacing ΔEL by dividing BW by 2 (i.e., ΔEL = BW/2).
- We scanned one range gate (250 m depth) through the center of Burgers-Rott vortices having various maximum tangential velocities (V_x) and core diameters (CD). Table 1 presents various-sized analytical vortices.
- We placed each vortex at 1º increments across a 90º-wide azimuthal sector and at 1-km increments from 1 to 240 km range (earth curvature).
- For tornadoes, we computed the difference between the peak positive and negative velocities.
- For mesocyclones, we computed the average peak tangential velocity from peak positive and negative Doppler velocities across the azimuthal profile.
- We conducted a few experiments to investigate the role of beam broadening on the detection of vortices.
- In the first experiment, we scanned each vortex at 1º increments across a 90º-wide azimuthal sector and at 1-km increments from 1 to 240 km range (earth curvature) at a lowest elevation angle, as indicated by an orange rectangle in the **figure on the right**.
- In the second experiment, we repeated the first experiment, except that we placed each vortex at the highest elevation angle, as indicated by a green rectangle in the **figure on the right**.
- This figure was never addressed in the Brown and Wood (2012) work.



Comparative Results

- In the experiment 1, the **figure on the right** shows how normalized peak Doppler velocity differences (tornadoes) and peak rotational velocities (mesocyclones) at the lowest elevation angle and broadside beamwidth BW_o = 1.5° decrease away from the broadside azimuth (0º) perpendicular to the antenna face (vertical 1.0 dashed line) as a function of range and azimuth (Brown and Wood 2012).
- The worst-case scenario is that phased-array broadside beamwidth of 1.5º results in weaker rotational velocities (solid contours) than those detected by the super-resolution WSR-88D (vertical dashed line).
- Except close to the radar, the velocity differences (a, b) for the two tornadoes degrade about the same, independent of range or beamwidth because the tornadoes are smaller than the beamwidths.
- Peak mesocyclone rotational velocities degrade with range because the vortices are larger than the smaller beamwidths at most ranges.
- The **figure on the right** explains how the Doppler velocity signatures become weaker than the true (simulated) vortex values as a function of range and beamwidth.
- Broadside beamwidth of 1.5° results in weaker rotational velocities (shaded bands) than those detected by the superresolution WSR-88D (dashed curves).

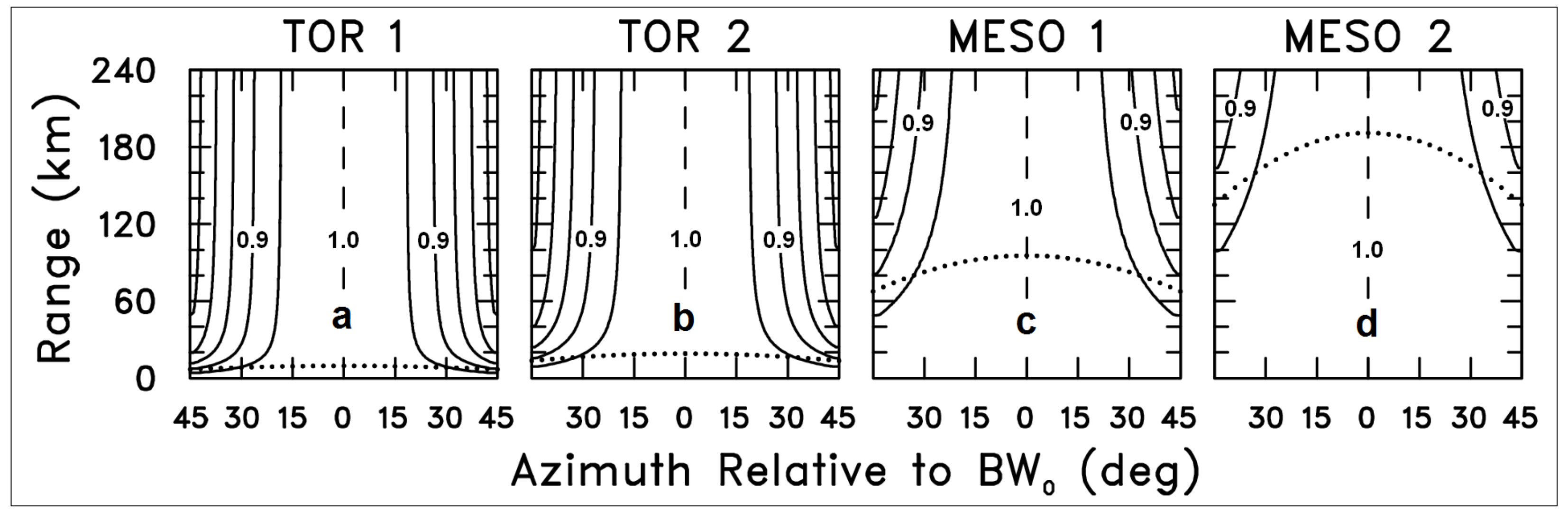
- The comparative results in the second experiment were not presented due to limited space on the poster. We will continue this going-on work.

Table 1

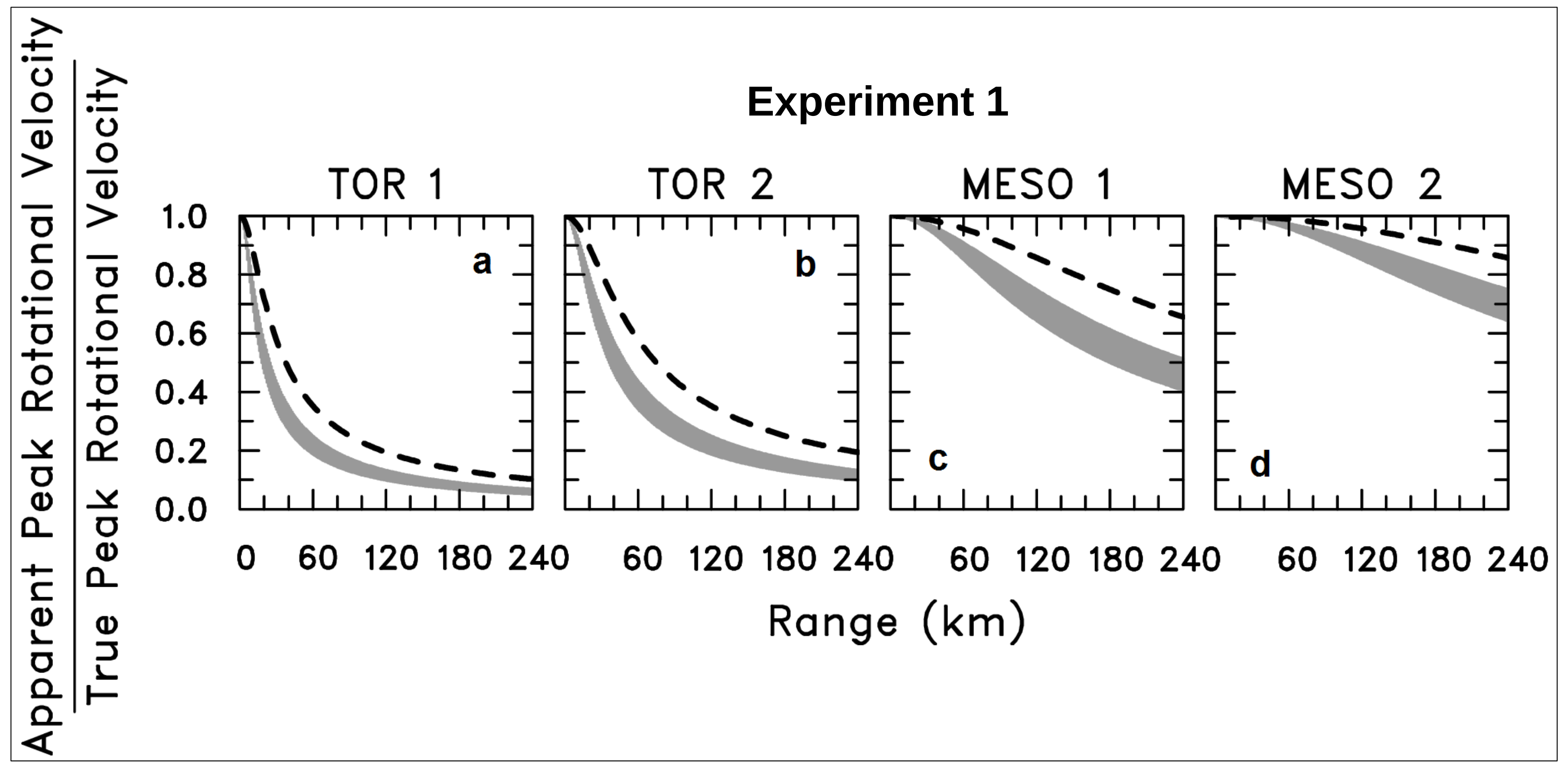
Vortex	**V_x** (m s^{-1})	**CD** (km)
Tornado 1 (TOR 1)	100	0.25
Tornado 2 (TOR 2)	75	0.50
Mesocyclone 1 (MESO 1)	50	2.50
Mesocyclone 2 (MESO 2)	25	5.00

Maximum tangential velocity (V_x) and core diameter (CD) for the two tornadoes and two mesocyclones used in the simulations. These values are a small sample of the wide range of tornado and mesocyclone characteristics. (After Brown and Wood 2012)

Experiment 1



Ratios of peak Doppler velocity differences associated with simulated tornadoes (a, b) and of peak rotational velocity signatures associated with simulated mesocyclones (c, d) relative to the simulated broadside values as a function of range and off–broadside azimuth angle for a given broadside beamwidth (BW_o) of 1.5º. Contour lines are at ratio intervals of 0.05. Curved dotted line indicates range (R) at which beamwidth is equal to the core diameter (CD) of the vortex specified by R = (57.296º CD / BW_o) cos θ. (After Brown and Wood 2012)



Ratios of the apparent peak rotational velocity to the true peak rotational velocity for Tornadoes 1 (a) and 2 (b) and Mesocyclones 1 (c) and 2 (d) as a function of range for a given broadside beamwidths (BW_o) of 1.5º. The shaded band represents the spread of ratios between the azimuth angle at BW_o and the transitional azimuth angle of ±45º. The dashed curve represents the WSR–88D super–resolution effective beamwidth of 1.0°. (After Brown and Wood 2012)

Conclusions and On-Going Work

- We presented the results of the impact of using a virtual PAR on vortex simulations.
- We will continue this work by placing the vortices at different elevation angles other than the lowest elevation angle, as indicated by the green rectangle in the **figure on the left**, for example.

References

Brown, R. A., and V. T. Wood, 2012: Simulated vortex detection using a four-face phased-array Doppler radar. *Wea. Forecasting*, **27**, 1598-1603.

Doviak, R. J., and D. S. Zrnić, 1993: *Radar and Weather Observations,* 2nd ed. Mineola, NY, USA: Dover Publications, Inc., 562 pp.

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