11A.4 RADAR ESTIMATED WINDS FOR THE 20 MAY 2013 MOORE, OKLAHOMA, TORNADO

Donald W. Burgess[1], K.L. Ortega[1], V.T. Wood[2], and V.M. Melnikov[1]

[1]University of Oklahoma, Cooperative Institute for Mesoscale Meteorological Studies (CIMMS)
[2]NOAA/National Severe Storms Laboratory, Norman, OK

1. INTRODUCTION

On 20 May 2013, a tornado affected the cities of Newcastle, Oklahoma City, and Moore, in Oklahoma. The pathlength of the tornado was 23 km and the damage width was up to 1740 m wide (Fig. 1). The tornado (forming in Newcastle at 1956 UTC) was initially wide and strong, mostly EF3 on the Enhanced Fujita (EF) Scale (WSEC 2006). As it approached Moore and continued through the western portion of the city, its intensity increased, producing a wide and continuous area of EF4 damage with small areas of EF5 damage. Near the center of Moore (just west of Interstate 35), the tornado briefly slowed and performed a loop before continuing on eastward. After the loop in east Moore, the path was considerably less wide, but still with a narrow, continuous area of EF4 damage. East of Moore, the tornado weakened and dissipated at 2035 UTC. The path of the tornado and its damage are documented (Burgess et al. 2014 and Atkins et al. 2014).

Several radars in central Oklahoma scanned the tornado at close range: the operational TDWR (KOKC), the long-term test WSR-88D (KOUN), the short-term test WSR-88D (KCRI), and the operational WSR-88D (TKLX). Locations of the radars are shown in Fig. 1. Data from each of the radars have been analyzed in order to estimate maximum wind speeds seen in association with the tornado.

Two additional central Oklahoma radars scanned the tornado. Data from the NSSL PAR are presented in Wood et al. 2014. Data from the University of Oklahoma PX-1000 are presented in Kurdzo et al. 2014).

2. RADAR CHARACTERISTICS

Information about radars used in the analysis is contained in Table 1. TOKC was operating in its severe-convective-weather mode. KCRI was operating in VCP 12 test mode, testing a new software build that contained Supplemental Adaptive Intra-Volume Low-level Scan (SAILS; ROC 2012) code. SAILS produces an extra 0.5 deg scan in the middle of the VCP. During VCPs during the tornado, SAILS was sometimes on and sometimes off. KOUN was operating in a special test mode of the VCP 11 mode, operating within sectors nearly 180 deg. in width that took about 2 minutes to accomplish. KOUN also collected time series data from which spectra were calculated. KTLX was operating in VCP 12. Note that pulse volume sizes were calculated for the time of maximum tornado intensity (~2017:30 UTC; see below).

Since the tornado for a lot of its life was moving nearly perpendicular to radial beams of several of the radars, maximum ground-relative radar wind estimates were calculated as a combination of the rotational velocity (V_r) and translational velocity (V_{tr}). This was to account for the fact that the strongest winds would be expected on the right flank of the tornado. For this case for an eastward moving tornado, that would be directed from west to east on the south side, and largely missed by the northward directed radials.

Maximum rotational velocities (max inbound plus outbound radial velocities divided by 2) associated with tornado signatures were found. See Fig. 2 for an example of velocity values that were used. In general, max inbound and outbound velocities were separated by multiple radials, not gate-to-gate, except for KTLX scans (farther range to the tornado), and for all radars near the end of the tornado when it was quite narrow. Tornado translational velocity was calculated from TOKC data because more rapid low-level revisit times gave it the best estimate of tornado horizontal motion.

3. RESULTS

3.1 In General

For all radars at all times during the tornado, maximum tornado wind speeds are found on the lowest elevation angle (0.5 deg. elev.). Results (Fig. 3), display estimates for all radars overlaid on damage path width and tornado translational motion. As expected, stronger wind speeds are seen from radars with smaller pulse volume sizes that come from closer range to the tornado, larger antenna dimensions, and favorable signal processing parameters (e.g. pulse length). All radars show the same trend of lower wind speeds early in tornado life, increasing winds to an intensity maximum between 2010 and 2020 UTC, and weakening winds thereafter.

TOKC, the closest radar and the one with the smallest pulse volume size, displays the highest tornado wind speed estimates, peaking at 86 m/s at 2017:30. The speeds are somewhat higher than those for KCRI and KOUN, at intermediate range, and considerably higher than KTLX at the longest range from the tornado. Although KCRI and KOUN are at the same range, KCRI

*_Corresponding author address:_ Donald W. Burgess, National Weather Center, CIMMS, 120 David L. Boren Blvd., Norman, OK, 73072-7307; email: donald.burgess@noaa.gov

winds are slightly higher. This is thought to result from KCRI having a slightly narrower effective horizontal beam width, and from KCRI displaying data at 0.5 deg azimuthal increments. The so-called "super-resolution" 0.5 degree delta azimuth does not change the pulse volume size, but overlapping beam centers depict more mean estimates, favorable for finding the best geometry of pulse volume location with respect to the maximum radial velocities. The least signal for the tornado (i.e. the change in velocity with respect to time) comes from KTLX, the radar at the longest range to the tornado. The longer range in this case is still relatively close to the radar (12-33 km range). Even less tornado signal might be expected for tornadoes at longer ranges (50 km and greater).

All radars indicate dramatic decreases in wind speed estimates at about 2022 UTC. This is the time when the tornado rapidly shrank in diameter and briefly became stationary while executing a path loop. Wind speed estimates after the loop, even with increased forward motion, do not return to previous higher values. This is in opposition to the damage survey (Fig. 1) that found continued violent tornado damage (EF4) for several kilometers east of the loop. The strong suggestion in these results is that the dramatic narrowing of the path (EF4 damage width consistently measured at only 20 to 40 m wide) produced maximum winds too small to be sampled by any of radars, even TOKC.

Unfortunately, looks at KOUN spectra were not revealing with respect to gaining further information about tornado wind speeds. The small KOUN Nyquist co-interval (+/- 32 m/s) produced considerable aliasing of highest and lowest radial velocities, rendering no way to de-convolve the overlaid spectral components.

3.2 Comparison with EF-Scale Winds

Comparing tornado winds estimated by radar to EF-Scale winds is difficult. EF-Scale winds are defined at 10 m height and are for 3-second duration (WSEC 2006). Winds for the radar with the best combination of short range and small sample volume size (TOKC) are likely dominated by returns from the top half of the radar beam because of blockage of the lower part of the beam and interference between earth-grazing radar rays. For the time of maximum intensity (and coincident closest approach to TOKC), that means the observations are approximately 40 to 80 m AGL.; certainly higher than 10 m with no accepted method to reduce the measurements to 10 m AGL height.

The situation is somewhat better with respect to 3-second duration as time-to space-conversion can be used to convert very rapidly acquired radar estimates over a point to winds of 3-second duration over the point. TOKC pulse volume size and tornado motion calculation (not shown) suggests that 3-second winds can be achieved by averaging two adjacent pulse volumes. Doing that for the maximum wind estimate and adding spectrum width, gives a 3-second wind range of 77.8 m/s to 89.8 m/s.

4. Discussion

At first look, there is near agreement between the maximum EF-Scale estimated wind (limited EF5 damage might occur with winds not much over 90 m/s), and the maximum radar estimated wind (78 – 90 m/s). However, there are several issues that complicate assigning any agreement between measurements:

1. The radar estimated winds are not at 10 m height. 10 m winds might be lower or higher in magnitude.
2. The Moore tornado moved through urban areas and generated large amounts of debris. The debris might dominate other scatterers within the radar sample volumes and debris centrifuging might contaminate the radar measurement of air motion. If radar samples are within the top of the tornado boundary layer (near where strongest horizontal winds are believed to reside) the velocity pattern should be convergent (Wurman et al. 2013). Only 13% of the TOKC scans showed a convergent pattern. This suggests likely problems with assuming estimates are measuring air motion.
3. The size/location of the radar sample volumes might be too large/mis-placed to capture small regions of highest winds.
4. EF-Scale wind values were obtained through a solicitation process and have not been independently verified (Edwards et al. 2013). The 90 m/s boundary between EF4 and EF5 might be too high or too low.

Work will continue to better understand radar tornado wind measurements and EF-Scale winds.

5. ACKNOWLEDGEMENTS

Funding for CIMMS authors was provided by NOAA/Office of Oceanic and Atmospheric Research under NOAA-University of Oklahoma Cooperative Agreement NA11OAR4300072, U.S. Department of Commerce.

6. REFERENCES

Atkins, N.T., T. Butler,R. Flynn, and R.M. Wakimoto, 2104: An integrated damage, visual, and radar analsysis fo the 2013 Moore, Oklahoma, EF5 tornado. *Bull. Amer. Meteor. Soc.*, doi: 10.1175/BAMS-D-14-00033.1, in press.

Burgess, D., K. Ortega, G. Stumpf, G. Garfield, C. Karstens, T. Meyer, B. Smith, D. Speheger, J. LaDue, R. Smith, and T. Marshall, 2014: 20 May 2013 Moore, Oklahoma, Tornado: Damage survey and analysis. *Wea. Forecasting,* **29**, 1229-1237.

Edwards, R.j., J.G. LaDue,J.T. Ferree, K. Scharfenburg, C. Maier, and W.L. Coulbourne, 2013: Tornado intensity estimation: Past, present, and future. *Bull. Amer. Meteor.Soc.*, **94**, 641-653.

Kurzo, J. M., D.J. Bodine, B.L. Chong, and R.D. Palmer, 2014: High temporal resolution polarimetric radar observations of the 20 May 2013 Newcastle-Moore, Oklahoma, EF-5 tornado using the PX-1000. 27th

Conf. on Severe Local Storms, Madison, WI, AMS, 11A.3.

ROC, 2012: Available from: http: //www.roc.noaa.gov/WSR88D/PublicDocs/NewTechnology/Supplemental_Adaptive_Intra_Volume_Low_Level_Scan_Description_Document_Final.pdf

Wood, V.T., P.L. Heinselman, R.A. Brown, David L. Priegnitz, D.W. Burgess, and C.D. Karstens, 2014: Analysis of Terminal Doppler Weather Radar and Phased Array Radar velocity and reflectivity signatures of the 20 May 2013 Moore, Oklahoma, Tornado. 27th Conf. on Severe Local Storms, Madison, WI, AMS, P116.

WSEC, 2006: A recommendation for an enhanced Fujita (EF-Scale). Wind Science and Engineering Center Tech Rep., Texas Tech University, 95 pp.

Wurman, j., K. Kosiba, and P. Robinson, 2013: In situ, Doppler radar, and video observations of the interior structure of a tornado and the wind-damage relationship. *Bull. Amer. Meteor. Soc.,* **94**, 835-846.

Radar	Band	Range	Effective Horiz. BW	Vertical BW	Gate Length	Pulse Volume	Delta Azimuth	0.5 deg elev revisit times
		km	deg.	deg.	m	m**3	deg.	Sec.
TOKC	C	11-5-12	1.2	0.5	150	6.8x10**5	1.0	30 or 60
KCRI	S	16-11-13	1.1	1.0	250	1.0x10**7	0.5	140 or 280
KOUN	S	16-11-13	1.3	1.0	250	1.2x10**7	1.0	120
KTLX	S	33-23-12	1.1	1.0	250	4.4x10**7	0.5	256

Table 1. Characteristics of radars used in the analysis. TOKC is the Oklahoma-City area operational Terminal Doppler (TDWR). KCRI is the short-term test WSR-88D. KOUN is the long-term test WSR-88D. KTLX is the central Oklahoma operational WSR-88D. Ranges listed are those at the beginning (1956 UTC), maximum intensity (2017 UTC), and ending (2035 UTC) of the tornado. The Pulse Volume Size is calculated for the time of maximum intensity.

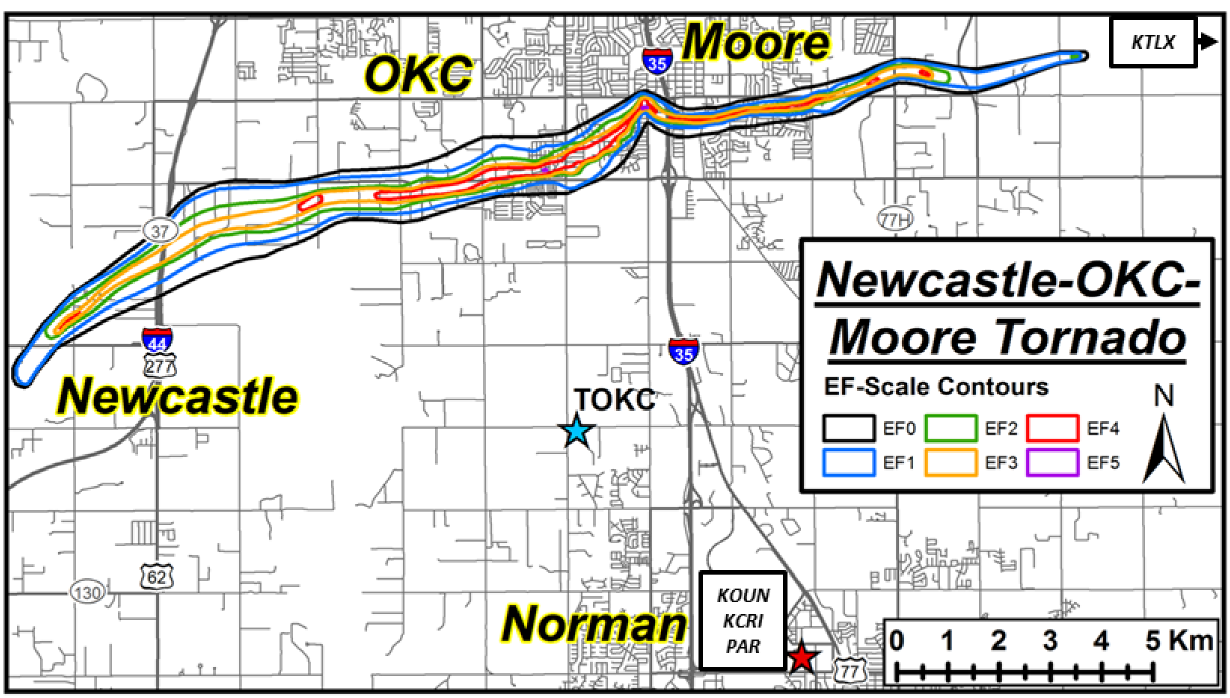

Fig. 1. Path of the 20 May 2013 Moore, Oklahoma, tornado. EF-Scale is contoured. Locations of radars mentioned in the text are shown. Cities in central Oklahoma are highlighted.

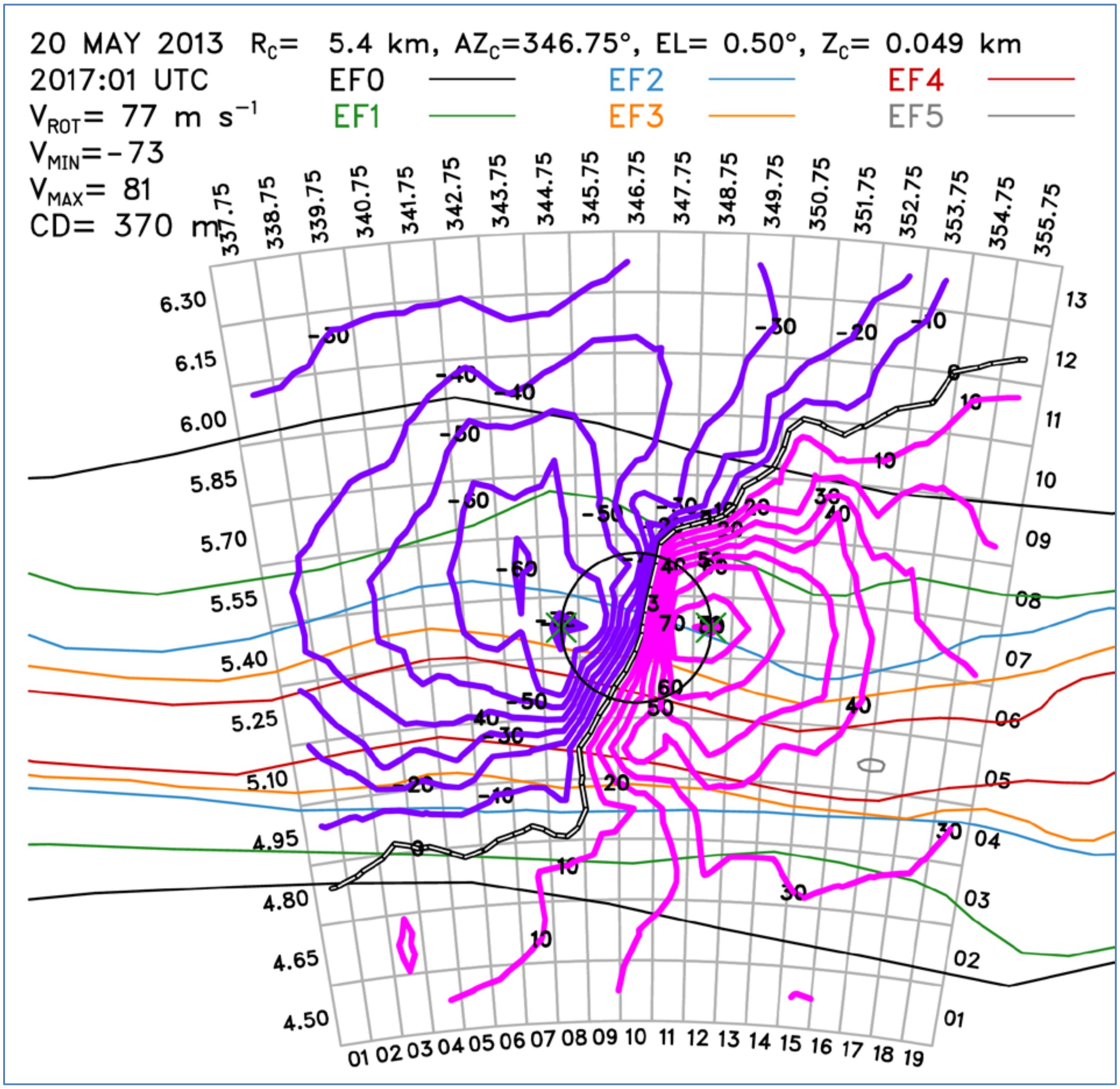

Fig. 2. TOKC radial velocities for 2017:01 UTC. EF-Scale damage contours are overlaid. "X" marks maximum inbound and outbound radial velocities, and solid circle approximates the tornado core diameter.

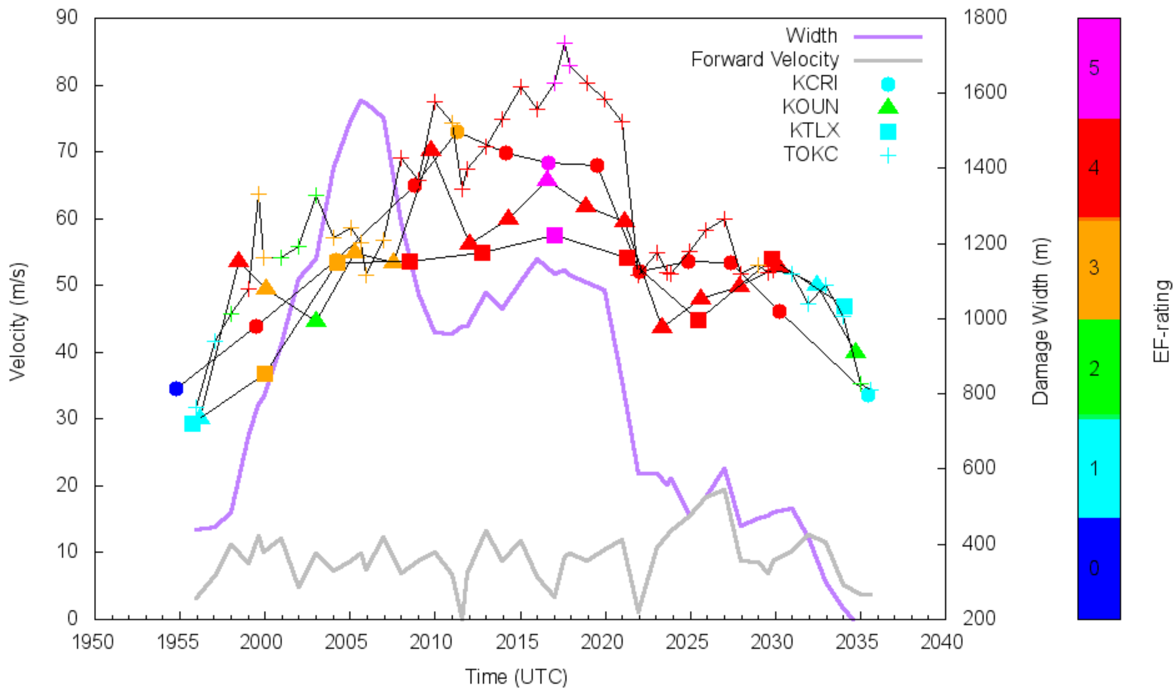

Fig. 3. TOKC, KCRI, KOUN, and KTLX winds as a function of time for the 20 May 2103 Moore tornado. Overlaid are tornado damage path width and tornado forward motion. Each radar plotted point has the color of the EF-Scale rating valid at radar observation time (scale at right).