134 A TOOL FOR REAL-TIME ESTIMATION OF TORNADO DAMAGE INTENSITY

[1]Richard M. Mosier*, [1]Bryan Smith, [1]Richard Thompson, and [1,2]Chris Karstens

[1]NOAA/NWS/NCEP/Storm Prediction Center, Norman, Oklahoma
[2]School of Meteorology, University of Oklahoma, Norman, Oklahoma

1. Introduction

Several recent studies have explored the relationship between the near-storm environment, WSR-88D velocity signatures, and surveyed tornado damage intensity [Smith et al. 2015, Thompson et al. 2017, Cohen et al. 2018, Smith et al. 2020a, Smith et al. 2020b (hereafter S20a and S20b)] in an attempt to aid operational forecasters in estimating real-time tornado intensity. The fast-paced nature of an operational warning environment yields the need for tools capable of providing all of the relevant data from these studies in a quick and accessible format. This tool was developed to meet those needs.

2. Data

The background data used for this web-based tool is an amalgamation of the data from Smith et. al. 2015, Thompson et al. 2017, S20a and S20b. These studies established a robust methodology for relating WSR-88D rotational velocity (V_{rot}) to damage indicators (DIs) from the Damage Assessment Toolkit (DAT; Camp et al. 2010) and the environmental information from Storm Prediction Center (SPC) mesoanalysis data (Dean et al. 2006). Refer to S20a for more information about this dataset as well as discussion regarding the spatiotemporal matching of the nearest DIs to each of the 0.5º DI scans, and the use of DIs to estimate the potential wind field of a tornado.

3. Tool Development

Initial development of this tool began at the SPC in early 2019 as the utility of using the data from Smith et. al 2015 and Thompson et. al. 2017 in real-time was explored. This initial development also occurred as the research underpinning S20a and S20b was ongoing. Early results from those studies resulted in information provided in Figure 1.

The information in this figure was distilled into a webpage that allowed the user to input the observed V_{rot}, maximum STP within 80 km from SPC mesoanalysis, and population density to output a damage-based wind speed estimate range. The initial wind speed range output by the tool is represented by the red dots on Figure 1.

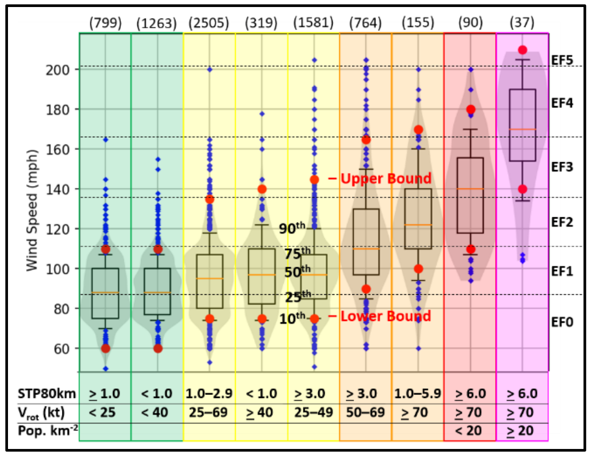


Figure 1. Empirical distributions of peak damage-derived wind speed, conditioned on nearest scan rotational velocity (V_{rot}), neighborhood-maximum effective-layer Significant Tornado Parameter within 80 km from SPC mesoanalysis (STP80km), and population density.

Additional data regarding the observed V_{rot} time duration (i.e., the number of consecutive scans at or above a particular V_{rot} value) was collected as the research for S20a and S20b continued. Results from this research, shown in Figure 2, revealed that using V_{rot} duration allowed for further refinement of the wind speed range for a full tornado path. This refinement was requested after the initial ranges spanned more than two Enhanced Fujita scale categories. This additional data was introduced into the webpage, which then had 5 inputs (Figure 3). Two of these inputs, population density and STP, are not updated rapidly, so the focus for the forecaster remains on storm-specific radar signatures that update every few minutes.

Considerations were also made during this time frame for how this tool could help forecasters decide which tags are needed with impact-based warnings (IBW). The NWS began issuing

* *Corresponding author address:* Richard Mosier, Storm Prediction Center, National Weather Center, 120 Boren Blvd #2300, Norman, OK 73072; E-mail: Richard.Mosier@noaa.gov

experimental IBW tags for tornadoes in 2012 as an action-item response to the 22 May 2011 Joplin, MO, EF5 tornado's severe assessment recommendation (NWS Central Region 2011). S20b addresses these considerations at length.

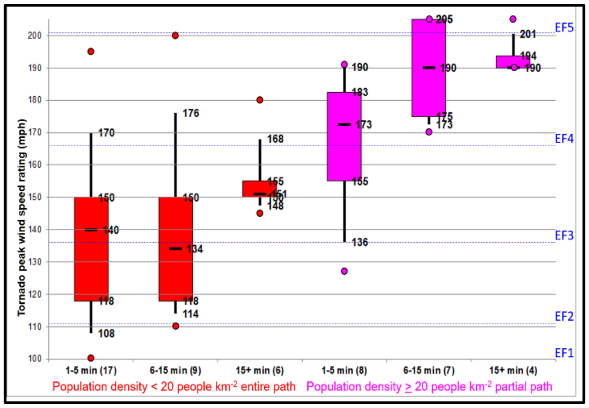


Figure 2. Box-and-whisker plot of peak damage-estimated wind speed (mph) by population density and duration (min) of Vrot ≥ 70 kt with STP80km ≥ 6. The 10th, 25th, median, 75th, and 90th percentiles are annotated with minimum and maximum values (circles). Sample sizes (bottom) for combined events from 2009–17 and 2019–20 samples.

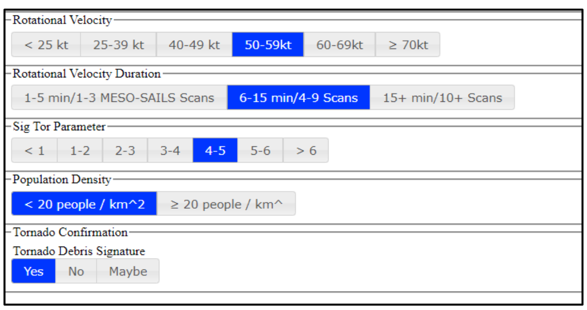


Figure 3. Example screenshot of the inputs needed for the web-based tool: 1) V_{rot}, 2) V_{rot} duration, 3) STP_{80km}, 4) Population Density, and 5) Presence of Tornadic Debris Signature.

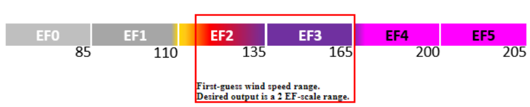


Figure 4: Example wind speed range estimate output from the tool (using the inputs shown in Figure 3).

The culmination of this additional research and development is shown in Table 1, which lists all the currently used inputs and outputs of the tool.

4. Example Output

For example, using the inputs shown in Figure 3: 1) V_{rot} between 50-59 kt, 2) V_{rot} duration of 6 to 15 minutes, 3) STP_{80km} of 4 to 5, 4) population density of less than 20 people per km^2, and 5) an observed tornadic debris signature (TDS; Ryzhkov et al. 2005), the current version of the tool outputs the images in Figures 5-8.

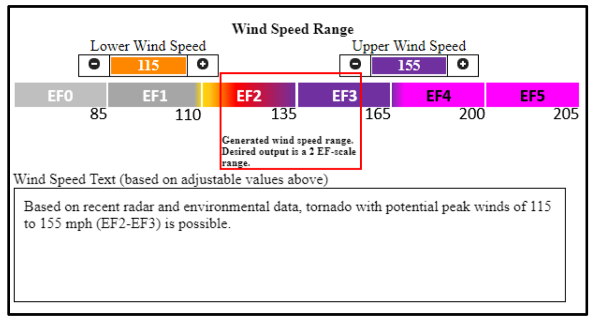


Figure 5. Wind speed range output from the V_{rot} tool.

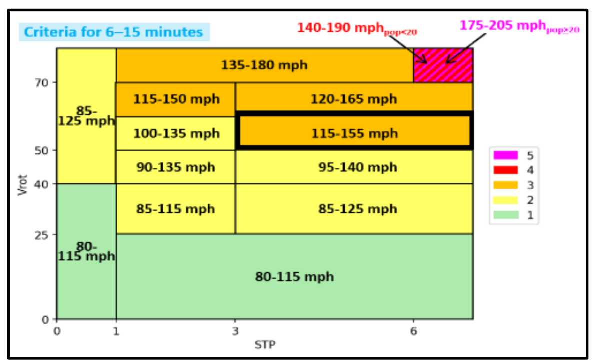
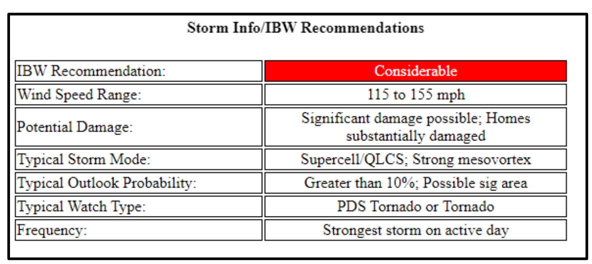


Figure 6. Secondary view of the wind speed range output from the V_{rot} tool.



Storm Info/IBW Recommendations

IBW Recommendation:	Considerable
Wind Speed Range:	115 to 155 mph
Potential Damage:	Significant damage possible; Homes substantially damaged
Typical Storm Mode:	Supercell/QLCS; Strong mesovortex
Typical Outlook Probability:	Greater than 10%; Possible sig area
Typical Watch Type:	PDS Tornado or Tornado
Frequency:	Strongest storm on active day

Figure 7. IBW recommendations from the V_{rot} tool.

Level	STP80km	Vrot (kt)	Duration (minute)	Pop. density (people km^{-2})	wind speed (mph) damage estimate	IBW recommender	potential damage	storm mode	Outlook tornado probability	Convective Watch (typical)	frequency
5	≥ 6.0	≥ 70	15+ 6–15 1–5	≥ 20	190–205 175–205 145–190	Catastrophic Catastrophic Catastrophic	Disaster potential Widespread destruction likely	Supercell (outbreak warm sector)	(≥ 10% sig)	PDS Tornado Tornado	Very rare (0–3 yr^{-1})
4	≥ 6.0	≥ 70	15+ 6–15 1–5	< 20	170–205 140–190 120–170	Catastrophic Catastrophic Considerable	Widespread destruction possible Significant damage likely	Supercell (outbreak warm sector)	(≥ 10% sig)	PDS Tornado Tornado	Rare (several yr^{-1})
3	1.0 – 5.9	≥ 70	15+ 6–15 1–5		150–190 135–180 120–165	Catastrophic Considerable Considerable	Significant damage possible Homes substantially damaged	Supercell (very intense)	(≥ 10%) possible sig	PDS Tornado Tornado	Strongest storm most days
3	≥ 3	60 – 69	15+ 6–15 1–5		125–170 120–165 115–155	Considerable Considerable Considerable	Significant damage possible Homes substantially damaged	Supercell (mature phase)	(≥ 10%) possible sig	PDS Tornado Tornado	Strongest storm most days
3	≥ 3	50 – 59	15+ 6–15 1–5		120–160 115–155 110–145	Considerable Considerable Considerable	Significant damage possible Homes substantially damaged	Supercell (mature phase)	(≥ 10%) possible sig	PDS Tornado Tornado	Strongest storm most days
3	1 – 2.9	60 – 69	15+ 6–15 1–5		125–160 115–150 110–140	Considerable Considerable Considerable	Significant damage possible Homes substantially damaged	Supercell (mature phase)	(2% – 15%) possible sig	Tornado Severe	Strongest storm most days
2	1 – 2.9	50 – 59	15+ 6–15 1–5		120–150 100–135 95–130	Considerable Base Base	Significant damage possible Homes/trees damaged	Supercell/QLCS strong mesovortex	(2% – 15%) possible sig	Tornado Severe	Common tornadic storm
2	1 – 2.9	40 – 49	15+ 6–15 1–5		115–145 90–135 85–120	Considerable Base Base	Significant damage possible Homes/trees damaged	Supercell/QLCS strong mesovortex	(2% – 15%) possible sig	Tornado Severe	Common tornadic storm
2	≥ 3	25 – 49	15+ 6–15 1–5		110–145 85–125 75–115	Considerable Base Base	Significant damage possible Homes/trees damaged	Supercell/QLCS strong mesovortex	(5% – 15%) possible sig	Tornado Severe	Common tornadic storm
2	< 1	≥ 40	15+ 6–15 1–5		110–140 85–125 75–115	Considerable Base Base	Significant damage possible Homes/trees damaged	Supercell/QLCS strong mesovortex	(<2% – 10%)	Tornado Severe No Watch	Common tornadic storm
2	1 – 2.9	25 – 39	15+ 6–15 1–5		100–125 85–115 75–110	Base Base Base	Significant damage possible Homes/trees damaged	Supercell/QLCS strong mesovortex	(2% – 10%)	Tornado Severe	Common tornadic storm
1	< 1	< 40	15+ 6–15 1–5		90–120 80–115 70–110	Base Base Base	Significant damage unlikely Minor damage homes/trees	weak Supercell /QLCS /Disorganized	(< 2% – 5%)	Tornado Severe No Watch	Weaker tornadic storm
1	≥ 1	< 25	15+ 6–15 1–5		90–120 80–115 70–110	Base Base Base	Significant damage unlikely Minor damage homes/trees	weak Supercell /QLCS /Disorganized	(< 2% – 5%)	Tornado Severe No Watch	Weaker tornadic storm

Table 1. Lists all the inputs and outputs used by the V_{rot} tool as of this publication.

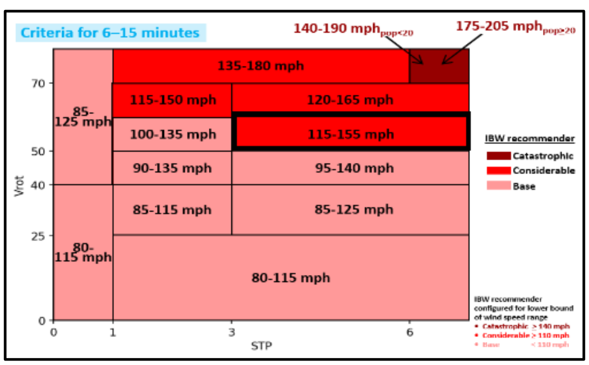


Figure 8. Secondary view of the IBW recommendations from the V_{rot} tool.

5. Verification

Smith et al. (2022) outlines a methodology used to verify this tool using damage-survey information from an independent sample of 99 tornadoes from 2020–2022. Results from this study are shown in Figures 9 and 10 (their Figure 6). This study reveals very promising results, with over two-thirds of the final, maximum damage-based wind speed estimates for the 99 tornadoes correctly identified within the predicted damage-based wind speed range. Greater than 80% of the tornadoes had a final maximum damage-based wind speed estimate within 10 mph of the predicted wind speed range. Thus, the tool provides reasonably accurate estimates of tornado wind speeds in real time, and can help inform IBW warning tags in a scientifically informed and nationally consistent manner.

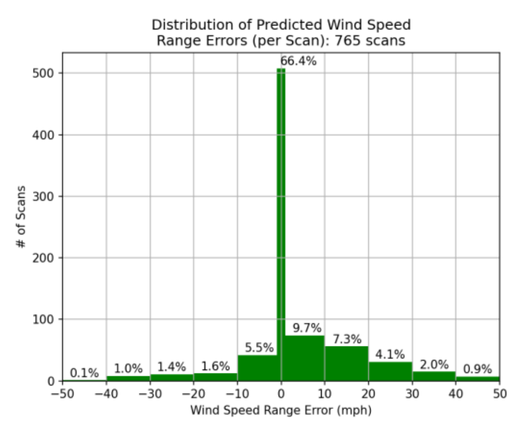


Figure 9: Histogram of the per scan predicted wind speed range errors in 10 mph bins. Positive (negative) values indicate an overestimate (underestimate) of wind speed compared to wind speed-based damage verification.

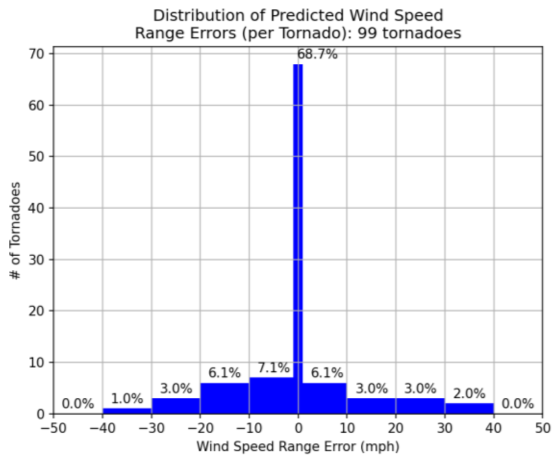


Figure 10: Histogram of the per tornado predicted wind speed range errors in 10 mph bins. Positive (negative) values indicate an overestimate (underestimate) of wind speed compared to wind speed-based damage verification.

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