Extended Abstract: A Comprehensive Analysis of Tornado Debris Signatures Associated with Significant Tornadoes from 2010-2017

Samuel W. Emmerson
University of Oklahoma, Norman, OK

Steven E. Nelson
National Weather Service WFO Peachtree City, GA

Adam K. Baker
National Weather Service WFO Peachtree City, GA

Abstract

This study is an extension of Nelson and Banghoff (2015) and Nelson et al. (2018) and includes a more comprehensive analysis of radar characteristics of TDSs. All significant tornadoes observed within 150 km of a WSR-88D radar with dual-polarimetric capability across the continental U.S. from May 2010 to December 2017 (N=511) were studied. Given a TDS was present, maxima in rotational velocity, azimuthal shear, TDS height and width, and minimum correlation coefficient values were collected. These variables were compared to observed maximum wind speed estimates and path widths obtained from National Weather Service damage surveys via the Damage Assessment Toolkit (Camp et al., 2017). Using principal component analysis to choose predictors, a linear model was created between maximum TDS height, maximum azimuthal shear, and maximum wind speed, which yielded a strong multivariate correlation ($r^2 = 0.71$). When combined with percentile-based thresholds for discrimination between significant (EF2+) and violent (EF4+) tornadoes, the linear model could be used in the Impact-Based Warning (IBW) framework for tornado warnings issued by the NWS.

Introduction

The tornado debris signature (TDS) is a highly correlated area in space and time of reflectivity greater than 30 dBZ, a strong radial velocity couplet, copolar correlation coefficient (ρ_{hv}) less than ~0.85, and differential reflectivity (Z_{DR}) of ~1.0 dB (Schultz et al., 2012, and Van Den Broeke and Jauernic, 2014). After the dual-polarization upgrade to the WSR-88D network in 2011-2013, NWS forecasters have observed that the height of tornado debris signatures was typically higher for intense tornadoes than for weaker tornadoes, which was confirmed by Banghoff (2015). In addition, Smith et al. (2015) found that peak rotational velocity is a good predictor of tornadic intensity. However, the previously mentioned works are plagued by a small sample size, as they were only able to consider a 2-year period of nationwide dual-polarization data. This project builds upon this previous work and explores the potential relationships between tornado debris signature (TDS) characteristics and the intensity of the causative tornadoes with a more robust dataset over a larger period.

Methods

581 EF2+ tornado cases were investigated from 10 May 2010 to 31 Dec 2017. For each of the 581 events, the following was done:

- Determine closest radar site and distance from radar
- Filter out events which lack dual-polarimetric data
- Acquire WSR-88D Level II radar data
- Analyze for presence of TDS with GR2Analyst

For the cases in which a TDS was present, the following data was collected:

- Maximum TDS height and diameter
- TDS start and end times
- Maximum rotational velocity and diameter
- Minimum CC

Rotational velocity was computed as

$$V_{rot} = \frac{V_{r_{min}} + V_{r_{max}}}{2}$$

Azimuthal shear was computed as

$$Shear = \frac{V_{r_{min}} + V_{r_{max}}}{Circulation\ Diameter}$$

For all TDS cases, NWS storm surveys accessed via the Damage Assessment Toolkit (DAT) were utilized to record maximum rated windspeed and path length and width. These data were then aggregated with datasets previously created by Entremont, Schultz, and Banghoff, which included 105 TDS cases between 10 May 2010 and 31 Dec 2014, yielding a total of 404 tornadoes with a complete documentation of TDS information.

Results

Principal component analysis indicates that the first PC mostly summarizes peak wind speed, as seen in **Fig. 1**. In addition, TDS height, rotational velocity, and azimuthal shear all have similar first PC factor scores to peak wind speed, suggesting that all are good predictors of peak wind speed. Since azimuthal shear has a greater factor score for the second PC than rotational velocity, the linear model uses both it and TDS height to predict peak wind speed.

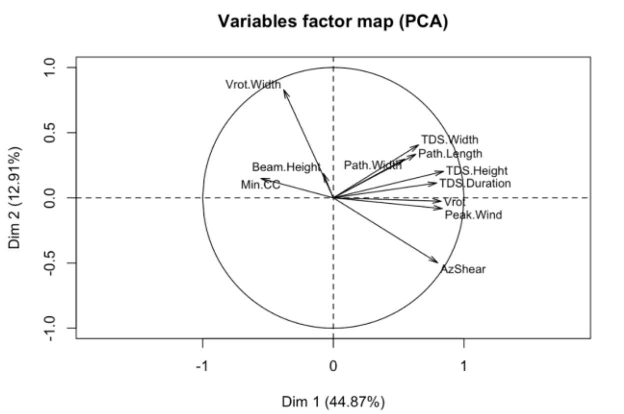

Figure 1: Variable factor map obtained from principal component analysis.

Based on **Figs. 2-3**, TDS height shows good discrimination between EF2-3 and EF4+ events, as EF4+ events all had TDS heights above 15 kft, with most above 20 kft. Overall, the correlation between TDS heights and estimated peak winds was found to be moderately strong ($r^2 = 0.59$). However, the correlation between azimuthal shear and peak estimated wind was weaker ($r^2 = 0.5$), perhaps due to noise in the azimuthal shear estimates.

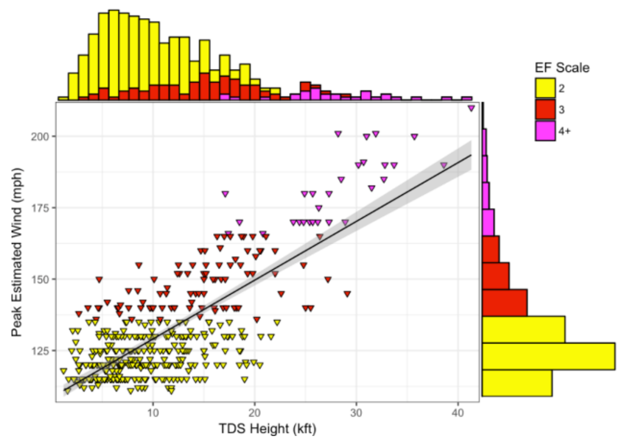

Figure 2. Scatterplot of maximum TDS height with maximum rated wind speed based on NWS survey.

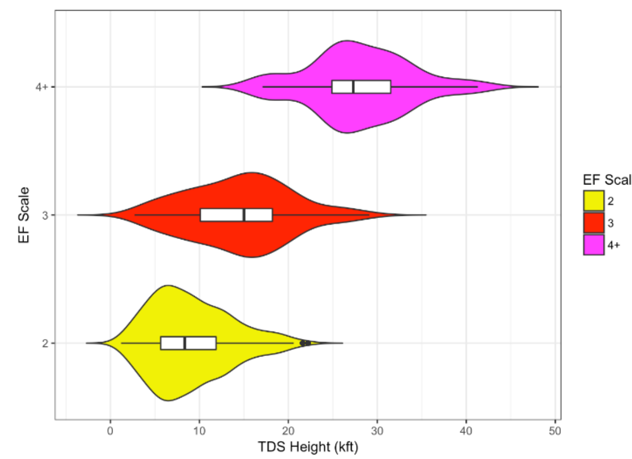

Figure 3. Violin plot of maximum TDS height grouped by EF scale rating.

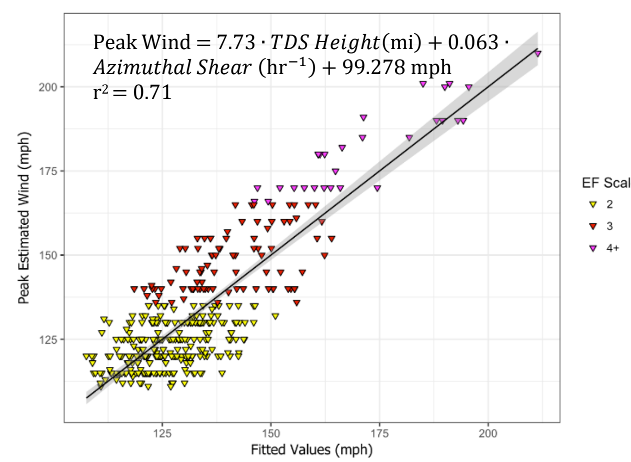

Figure 4. Scatterplot of fitted values from the linear model with maximum rated wind speed.

CONCLUSIONS

- TDS height, rotational velocity, and azimuthal shear are all good predictors of peak wind speed, as shown by PCA and correlation coefficients ($r^2 \approx 0.5$-0.6)
- TDS height yields good discrimination between EF2-3 and EF4+ events, particularly for heights above 15 kft
- Residuals from linear model fall within ±20 mph

FUTURE WORK

Short-term goals:

- Continue updating TDS database
- Investigate land use/vegetation type on TDS characteristics, as well as any seasonal/temporal dependence

Long-term goals:

- Examine EF0 and EF1 cases
- Collaborate with SPC to create TDS database supplemental to Storm Data
- Look into usage of TDS characteristics in Impact-Based Warning framework

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