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Developmental Work at the Storm Prediction Center in Pursuit of Tornadic Supercell Probability and Tornado Intensity Estimation Using a Severe Supercell Dataset

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ABSTRACT

The Storm Prediction Center (SPC) is developing both a tornadic and severe nontornadic sample of supercell storms from 2014. This latest work is an extension of earlier research which led to the development of conditional probabilities of tornado damage rating from near-storm environment and radar-based storm-scale characteristics from a 5-year sample of tornadoes (4,770) reported in the contiguous United States (CONUS) during 2009–2013.

The probabilities are derived from filtering tornado EF-scale segment data, large hail (i.e., ≥1 inch diameter), and severe wind gust (i.e., ≥50 kt) data by the maximum event type (e.g., tornado, hail, wind) per hour on a 40-km horizontal grid. Near-storm environment data, consisting primarily of supercell-related convective parameters from hourly objective mesoscale analysis calculated at the SPC, accompanied each grid-hour event. Filtered large-hail/wind events (~ 11000) associated with effective shear ≥20-kt and tornado events (800) were subsequently examined with level-II radar data. Convective mode was then assigned manually to each tornado large-hail/wind event if 0.5° velocity data from the nearest WSR-88D exhibited rotation. Peak 0.5° rotational velocity was recorded for each tornado event along the tornado path and within 10 minutes/miles for large-hail/wind reports.

Preliminary results of tornado probabilities based on 2014 severe supercell 40-km grid-hour data are presented. Implications of these findings for diagnosing tornado potential in near real-time and possibly applying this research to aid National Weather Service (NWS) Impact-Based Warnings are discussed —tentatively scheduled for operational adoption NWS-wide by early 2016.

1. Introduction

Numerous studies have associated reported tornadoes and large hail (≥1 inch diameter) and severe wind gusts (≥50-kt) to environments using proximity sounding data (e.g., Thompson et al. 2003, Rasmussen 2003). Thompson et al. (2012) provided the first single-site Weather Surveillance Radar – 1988 Doppler (WSR-88D) climatological examination of different convective modes (i.e., supercell, quasi-linear convective system) to tornadic environments. More recently, Smith et al. (2015) confirmed a relationship with tornado intensity, storm mode, 0.5° peak rotational velocity, and the

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environment. Yet, an environment and radar attribute dataset used to discern differences between severe-producing nontornadic supercells and tornadic supercells is currently lacking in the literature. This study strives to further explore velocity signatures and environments for tornadic and severe nontornadic supercells. A goal of this work is to provide probabilistic estimates of tornado occurrence and intensity via radar velocity attributes and storm environment information.

2. Data and Methodology

a. Event filtering

Radar-based convective modes, peak low-level rotational velocities, and near-storm environment data were assigned to a subset of large hail ($\geq$1 inch in diameter), severe wind gusts ($\geq$ 50-kt) or thunderstorm wind damage, and tornadoes reported in the contiguous United States during 2014. The severe hail, wind, and tornado data were filtered by the maximum hail size, gust speed, or EF-scale rating, respectively, per hour on a 40-km horizontal grid. Additional filtering would occur if 1) a hail (wind) event was located within 15 minutes and 10 nm of a tornado, or 2) a hail (wind) event was assigned the same 0.5° peak rotational velocity (V_{rot}) as a wind (hail) event.

b. Radar-based convective mode classification

This study follows the procedure outlined in Smith et al. (2012) for assigning convective mode. Using the nearest single-site WSR-88D radar data, manual storm classifications were determined at the beginning time of each tornado or at the time of the documented circulation used for the large-hail/wind reports. Convective mode was assigned by manually analyzing archived level-II single-site, full volumetric WSR-88D data (Crum et al. 1993) from the National Climatic Data Center (http://www.ncdc.noaa.gov/nexradinv/) using Gibson Ridge radar-viewing software (http://www.grlevelx.com/). While circulations from other convective modes were documented, only circulations from supercells and marginal supercells (Smith et al. 2012) are presented—which results in a sample of 328 tornado and 1272 large-hail/wind 40-km grid-hour events. For cases when relevant radar signatures did not correspond with report data, the authors made manual adjustments to a small portion of the database on a case-by-case basis and followed the methods used for alleviating errors described in Smith et al. (2015).

Archived environmental information (Dean et al. 2006), consisting primarily of supercell-related convective parameters from the hourly SPC objective analyses (Bothwell et al. 2002), accompanied each grid-hour event. The Rapid Refresh (RAP) model 0-h forecasts on a 40-km grid provided the basis for the SPC hourly mesoscale analyses. This study utilized the maximum neighborhood grid-hour value within 80 km (Potvin et al. 2010) of each tornado event for STP [hereafter STP_{80km}; Thompson et al. (2012)] to account for proximity concerns and spatial variability of environmental parameters, while providing a relatively simple characterization of the regional tornado environments that were dominated by supercells. The maximum neighborhood approach reflects the ability of the operational meteorologist to consider more than a single grid-point value, and to alleviate potential spatial errors in the model-based parameter fields. Therefore, STP_{80km} is used in this study as a single diagnostic to assess supercell tornado potential based on work by Thompson et al. (2012).

c. 0.5° circulation intensity identification

V_{rot} was manually analyzed, and the peak inbound and outbound velocities were examined for each volume scan from immediately prior to tornado formation through tornado dissipation. Only combinations of velocity maxima exhibiting cyclonic azimuthal shear within 5 nm and < 45° angle from one another were considered, to avoid primarily convergent or divergent signatures. The maximum 0.5° peak rotational velocity [$V_{rot} = (|V_{in}| + |V_{out}|) / 2$] from all volume scans was assigned to each tornadic event, and only events sampled ≤10000 ft above radar level (ARL; <101 mi range) were analyzed and included in this study (Fig. 1). While the importance of radar range dependency factors (e.g., beam width, velocity sampling height ARL) influencing the velocity–EF-scale relationship were confirmed in Smith et al. (2015), those factors are not presented herein. The addition of another ~½ year of cases using 2014 data is needed for attaining robust sample sizes to account for radar range dependency. Brief, short-track tornadoes were assigned 0.5° peak V_{rot} immediately prior to the start time for cases not persisting longer than one volume scan, whereas longer-lived tornadoes were assigned 0.5° peak V_{rot} from one of the sampling volume scans during the tornado event.

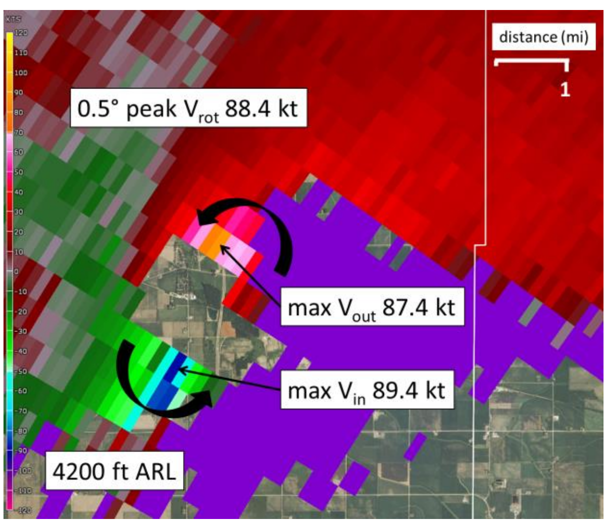

Figure 1. WSR-88D storm relative velocity (kt, color scale on left) at 0.5º beam tilt from the Romeoville, IL radar (KLOT) at 0004 UTC on 10 April 2015. Denoted inserts display maximum inbound storm relative velocity (max V_{in}, 89.4 kt), maximum outbound storm relative velocity (max V_{out}, 87.4 kt), and peak rotational velocity (max V_{rot}, 88.4 kt) sampled at 4200 ft above radar level (ARL). A right-moving supercell produced a 20.9 mile path length, 700 yard wide EF4 tornado segment (winds estimated at 200 mph) in Ogle County, IL. North is up; county border is white; distance scale (upper right); storm relative velocity (kt, scale on left); curved arrows signify rotation.

For a large-hail/wind event to be included in this dataset, the following criteria were required: 1) a subjective assessment of an identifiable circulation or cyclonic shear at 0.5° from a marginal supercell or supercell storm, and 2) the pertinent 0.5° velocity signature must have occurred ± 10 minutes and within 10 mi of the severe event location. Similarly to tornado events, only severe events with 0.5° velocity data within 10000 ft ARL (<101 mi range) of a WSR-88D were included in this study.

Potentially erroneous velocity data were excluded from consideration in obvious cases of 1) primarily non-meteorological scatterers in the storm inflow region (e.g., very weak reflectivity and cross-correlation coefficient data), 2) dealiasing concerns, and 3) side lobe contamination. The majority of the authors interrogated multiple cases which likely resulted in slightly varying interpretations of velocity data. For some of the more difficult individual cases, two meteorologists provided input on assigning velocity to best account for possible erroneous or misleading data.

Similar to the 2009–2013 tornadic storm sample, it was common for the 2014 velocity signatures to vary during the life cycle of the tornado event. Yet, the tornado events in this sample rarely had one outlier volume scan at 0.5° tilt with much stronger V_{rot} (i.e., ≥ 20 kt difference) compared to the other volume scans. Many of the higher-end tornado cases exhibited consistent velocity values that were just below the peak V_{rot} value for several volume scans, including a substantial part of the tornado segment grid hour (i.e., tornado event). Although there was a strong correspondence between the highest EF-scale rating and the maximum 0.5° peak V_{rot}, the two did not necessarily match in time and space [i.e., Bodine et al. (2013), Ladue et al. (2012)].

d. Tornado probabilities

Probabilities of tornado occurrence and intensity, as measured by EF-scale damage, are calculated using STP_{80km} and 0.5° peak V_{rot}. Given the large range in documented STP_{80km} (0-24), 0.5° peak V_{rot} (0-124 kt), and EF-scale (0-5), the sample sizes for paired values of STP_{80km} and 0.5° peak V_{rot} to EF-scale are severely limited in most cases. Therefore, each STP_{80km} value was placed within a bin (e.g., 4.00-5.99), and each 0.5° peak V_{rot} value below 100 kt was placed within a 10 kt bin (e.g., 60.0-69.9 kt). To summarize, 0.5° peak V_{rot} and STP_{80km} are both used as diagnostic variables for estimating the likelihood of a tornado and the potential tornado damage intensity.

3. Results and Operational Application

The results of this study are intended to be applied within the NWS Impact Based Warnings (IBW) operational warning framework (Hudson and Perry 2014). That is, a tiered warning structure affords forecasters the opportunity to distinguish between weak tornadoes and strong to violent tornadoes. The IBW tornado damage threat potential tiers are intended to correspond to tornado intensity as related to EF-Scale (i.e. Base, EF0-1; Considerable EF2-5; Catastrophic, EF4-5). For this study's results, the emphasis is on distinguishing the Considerable tier from the Base tier warning. The Catastrophic tag is a special case reserved for extremely rare events with absolute direct observational evidence of a violent tornado.

Preliminary findings of the partially completed 2014 severe event data show a general increase in probabilities for a given minimum EF-scale (e.g., EF1+) as values of STP_{80km} and 0.5° peak V_{rot} increase (Figs. 2–3). Considering storm environment alone (STP; Fig. 2), a severe-producing supercell (no confirmed tornado) with at least weak cyclonic shear at 0.5° and within an environment of 6.00–7.99 STP_{80km} yields a 14% (60%) probability of an EF2+ (no) tornado during that particular 40-km grid hour. Within the same 40-km grid hour environment bin (i.e., 6.00–7.99 STP_{80km}), the tornadic supercell sample yields a 34% probability for an EF2+ tornado event (Fig. 2). In other words, once a tornado is confirmed [e.g., dual polarization tornadic debris signature (DPTDS; Bodine et al. 2013) or trained spotter reports] with a severe-report producing supercell, it is appropriate to use the probabilities from the tornadic sample (i.e., dashed lines in Fig. 2). Hence, the probability of an EF2+ tornado event in the 6.00–7.99 STP_{80km} 40-km grid-hour environment changes from 14% to 34% with confirmation of a tornado. The environment-only data necessarily support lower tornado probabilities, and can serve as an estimate of potential false alarm ratios in the case of indiscriminant tornado warnings for supercells.

A similar exercise can be performed using only 0.5° V_{rot} data (Fig. 3). A 67-kt 0.5° V_{rot} assigned to the 60.0–69.9-kt bin with a yet-to-be confirmed tornado would yield a 39% (29%) probability of an EF2+ (no) tornado. If a tornado is subsequently confirmed, the probability of an EF2+ tornado event changes from 39% to 58% (Fig. 3). Note that about half of the supercells in this database with 0.5° Vrot in the 50.0–59.9-kt bin produce a tornado.

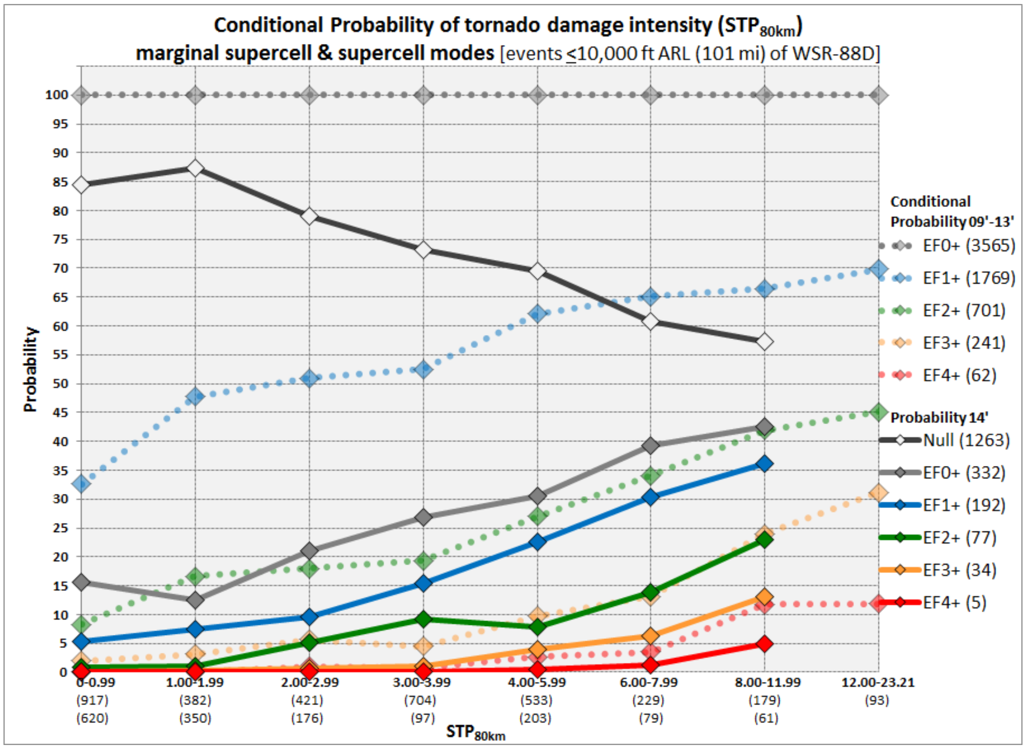

Figure 2. Conditional probability of meeting or exceeding a given EF-scale rating (legend) for STP_{80km} (dimensionless; x-coordinate; sample size) for marginal supercell and supercell mode tornado events (2009–13; dashed curves) and all severe event types (2014; solid curves) at ≤10 000 ft ARL, with 1–101-mi radius].

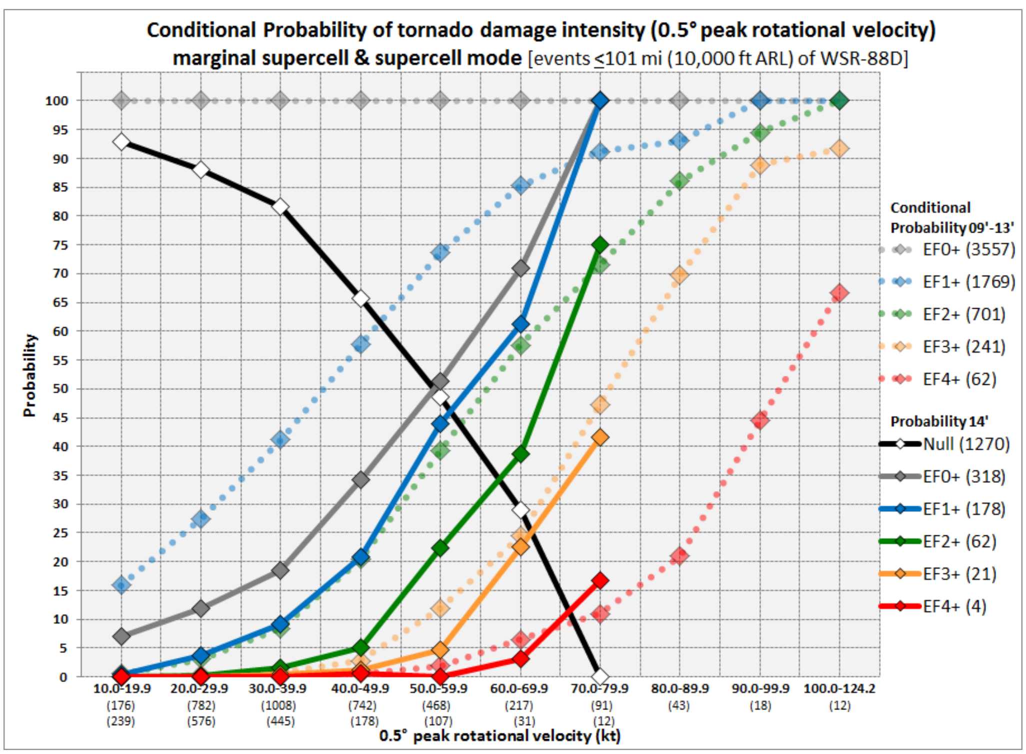

Figure 3. As in Fig. 2, but for 0.5° peak V_{rot} (kt; x-coordinate).

4. Discussion

It is acknowledged that the ranges and frequency distributions of 0.5° peak V_{rot} and STP_{80km} shown in Figs. 2 and 3 are related to the criteria of identifying nontornadic events (e.g., at least weak cyclonic shear at 0.5°, with likely beam height dependency both close to and far from a radar site). Although the probabilistic values for the 2014 data will likely change some as the sample size increases for each bin of STP_{80km} and 0.5° peak V_{rot}, the initial probability distributions appear fairly robust based on analysis of roughly half of the 2014 grid-hour events. Nonetheless, caution should be exercised in using exact probabilities because the data is still considered preliminary and is *subject-to-change* as more cases are added.

Tornadoes from nonsupercell modes (i.e., QLCS) and nonmesocyclone "landspouts" (Brady and Szoke 1989) are not the focus of this study, by virtue of these type of tornado events being both fewer in number and generally weak (Smith et al. 2012). Future work will examine the potential to develop similar storm environment and V_{rot} probability distributions for QLCS mesovortices and nonmesocyclone tornadoes, given the typically smaller circulations that may not be resolved as well as their supercell counterparts.

Perhaps additional confidence may be gained by a forecaster when assessing radar in real-time if multiple scans meet or exceed a probability threshold. Finding #10 in the Joplin, Missouri, Tornado Service Assessment (NOAA, 2011) highlighted the impact infrequently updated 0.5° velocity data had on the NWS' ability to have a more rapid, subjective determination of the tornado intensity. The probabilities discussed herein can be used to assist in diagnosing or anticipating thresholds for different IBW tiers. Following recommendation #10—emphasizing the need for rapid (~1 min) 0.5° velocity updates to assist in monitoring of tornadogenesis and rapid changes in tornado intensity—NWS radar scanning strategy has evolved. The operational deployment of the AVSET (Automated Volume Scan Evaluation and Termination) and SAILS (Supplemental Adaptive Intra-Volume Low-Level Scan) scanning strategies in Volume Coverage Pattern (VCP) 212 has resulted in 0.5° velocity scans every 118s–162s, depending on the AVSET termination angle (ROC, 2015a). Therefore, on a case-by-case basis, it appears possible to probabilistically estimate tornado intensity and/or discriminate a potential tornado threat on the order of minutes by combining situational awareness of the near-storm environment, convective mode, velocity, and ground truth (Fig. 4). The following hypothetical scenarios illustrate the potential utility of such an approach: 1) a marginally supportive tornado environment (e.g., STP_{80km} ~1) and relatively weak 0.5° peak V_{rot} (e.g., 20 kt); 2) a more dangerous tornado environment (i.e., STP_{80km} ~8) and moderate 0.5° peak V_{rot} (e.g., 40 kt); 3) a dangerous tornado environment (i.e., STP_{80km} ~8) and strong 0.5° peak V_{rot} (e.g., 80 kt). The first scenario suggests that significant tornadoes are unlikely. The second scenario supports a greater conditional risk of significant tornadoes, though confidence is lower given the modest V_{rot}. The third scenario indicates a high likelihood in the risk of significant tornadoes, both through the examination of the storm environment and consideration of radar velocity signatures, giving the warning forecaster confidence in assigning a Considerable tag in the IBW framework.

This multi-variable probability approach can be applied within the IBW framework diagnostically to estimate the tornado threat through usage of tag statements within Severe Weather Statements (SVS) and tornado warnings. Additional radar improvements scheduled for nationwide deployment in early 2016 will result in 0.5° velocity scans every 72s–90s (ROC, 2015b), permitting multiple 0.5° scans to temporally smooth fluctuating probabilities or gain confidence in particular values of 0.5° V_{rot}.

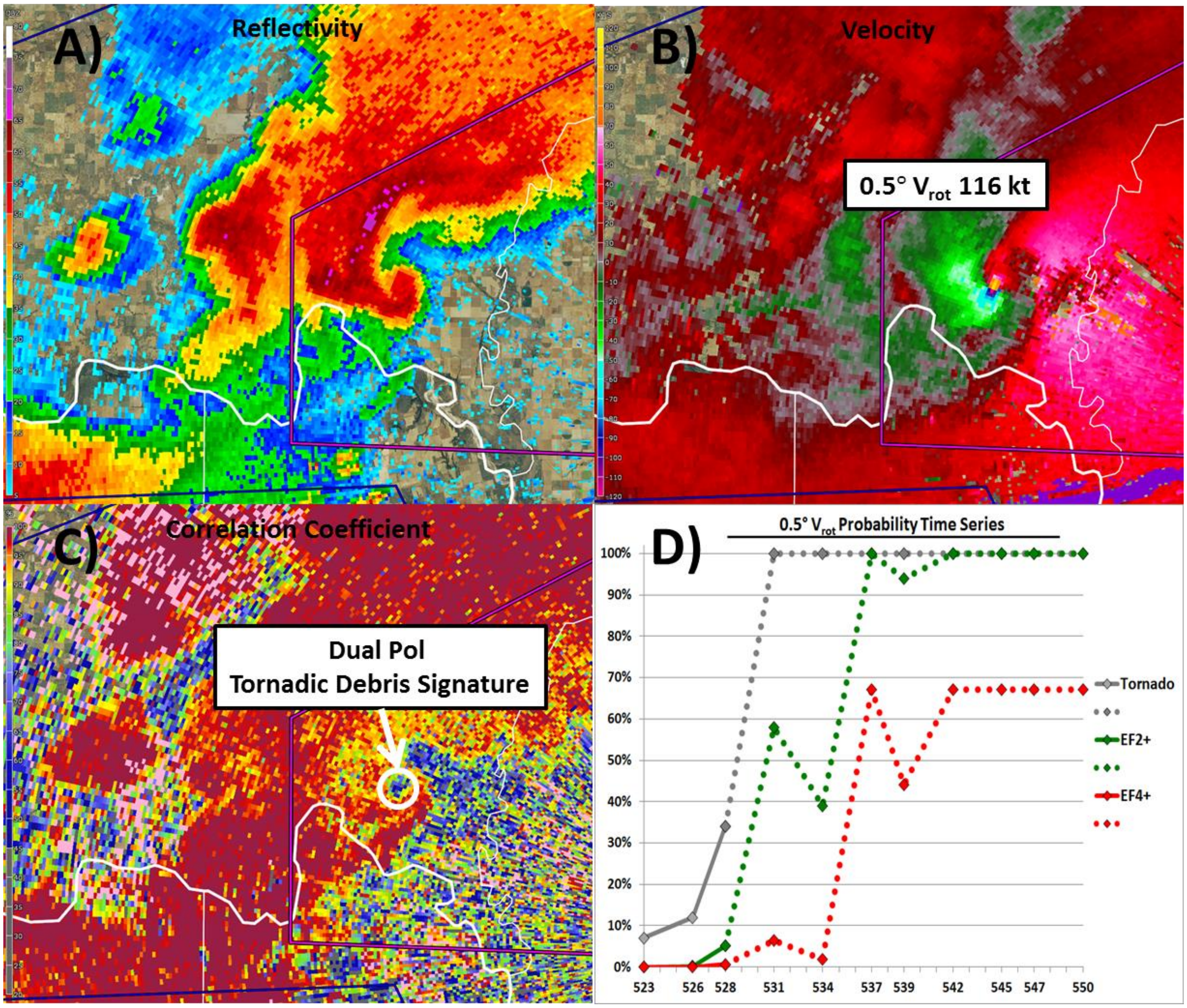

Figure 4. (a) WSR-88D base reflectivity (dBZ; color scale on left) at 0.5° beam tilt from Frederick, OK (KFDR), at 552 CDT 16 May 2015. A right-moving supercell in Tipton County, OK produced a 9.6 mile path length, 1600 yard wide EF3 tornado segment and StormData mentioned it as "likely violent" based on radar and video evidence. (b) Similar to Fig. 1 except 0.5° V_{rot}, 116 kt. (c) Correlation coefficient (kt, scale on left); minimum values annotated to signify a dual pol tornadic debris signature. (d) Time series (523 pm CDT – 550 pm CDT) with values of V_{rot} (not shown) associated with probabilities of a tornado, EF2+, and EF4+. Solid (dashed) curves signify the unconfirmed (confirmed) tornadic supercell probabilities from the 2014 (2009–2013) dataset.

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