Polarimetric Tornado Debris Signature Spatial and Temporal Characteristics

Matthew Van Den Broeke

Department of Earth and Atmospheric Sciences, University of Nebraska-Lincoln

Introduction

Background

Tornadoes may loft non-meteorological scatterers characterized by unique polarimetric radar signatures. The polarimetric debris signature includes correlation coefficient (ρ_{hv}) < 0.8, differential reflectivity (Z_{DR}) < 0.5, reflectivity factor (Z_{hh}) > 45 dBZ, and collocation with a hook echo and pronounced vortex diagnosed from radial velocity (Ryzhkov et al. 2005). In this study, all reported tornadoes in the domain of a polarimetric WSR-88D radar from Jan 2012 – May 2013 were examined for the presence of a debris-consistent signature, and spatial and temporal characteristics of signatures were explored.

Objectives

- Quantify *frequency of signature occurrence* as a function of geographic region, tornado intensity, property damage, and radar beam altitude
- Discover any *seasonal changes* in signature visibility
- Compare *signature areal extent* to property damage and 0.5-degree radar beam altitude

Methods

- All tornado events from 01/01/2012 through 05/31/2013 were identified using the NCDC Storm Events Database. For these events, a database was constructed including:
  - Beginning and ending time
  - Beginning and ending latitude/longitude
  - EF-scale, width, and county-level path length
  - Associated deaths, injuries, and crop/property damage

- The nearest polarimetric WSR-88D radar dataset was identified for each tornado event

- Radar data was visualized, and for each tornado event with data of acceptable quality, these attributes were recorded:
  - Convective mode
  - Presence or absence of debris signature
  - Distance to radar and altitude of radar beam (assuming 4/3 Earth radius model)
  - Time of maximum signature and signature longevity; other signature characteristics

- Maximum areal extent (km^2) of the signature was also estimated for each event at the 0.5-degree elevation angle

Results

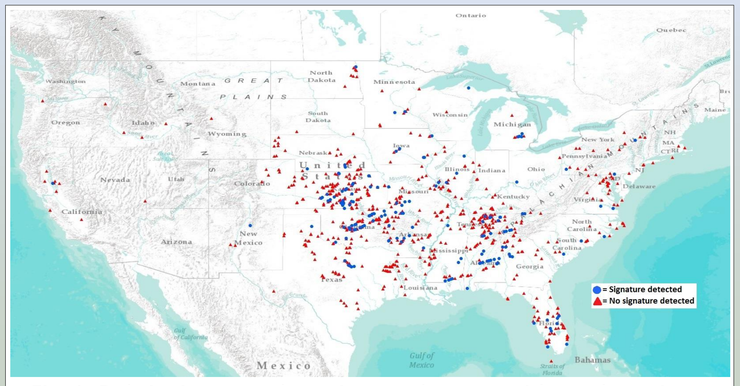


Fig. 1: Debris signature detections and events without detections.

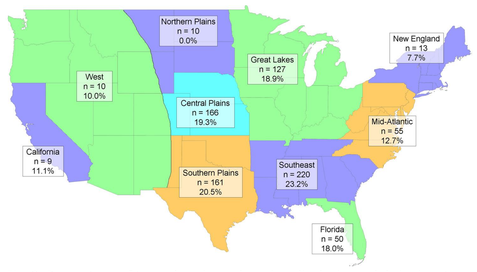


Fig. 2: Percentage of tornadoes in each region displaying a debris signature.

Seasonal Dependence

Season	n	Avg. Appearance After First Report (min)
Dec – Feb	13	6.3
Mar – May	77	**4.2**
Jun – Aug	18	5.2
Sept - Nov	11	2.0

Table 1: Time (min) to debris signature first appearance after reported tornadogenesis in different seasons.

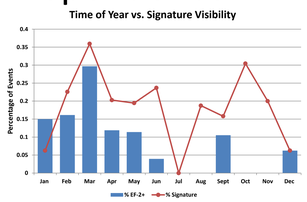


Fig. 3: Percentage of tornadoes with a debris signature in each month (red line), and percentage of tornado events rated EF-2+ (blue bars). Spring maximum likely corresponds to more strong tornadoes; fall maximum may correspond to greater natural debris availability.

Debris Signature Areal Extent

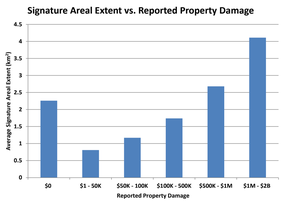


Fig. 4: Reported property damage compared to areal extent of associated debris signature. Signature extent rises exponentially with reported damage.

Classification	n	Avg. Areal Extent (km^2)
EF-0	31	1.77
EF-1	43	1.29
EF-2	28	**2.88**
EF-3	14	4.88
EF-4	4	**2.94**

Table 2: Average maximum areal extent of a tornado debris signature, for cases in which areal extent could be estimated, related to tornado intensity rating.

Relationship to Observational and Tornado Characteristics

Classification	n	Percent with Signature
EF-0	460	7.8%
EF-1	263	24.3%
EF-2	67	**56.7%**
EF-3	24	83.3%
EF-4	6	100%
EF-5	1	100%

Table 3: Percentage of tornadoes in each Enhanced Fujita Scale classification with a debris signature.

Property Damage	n	Percent with Signature
$0	393	16.3%
$1 – 10,000	83	12.0%
$10,001 – 100,000	205	12.7%
$100,001 – 500,000	92	**39.1%**
$500,001 - $1M	17	64.7%
$1M - $10M	20	55.0%
$10M - $2B	11	81.8%

Table 4: Percentage of tornadoes in several property damage categories with a debris signature.

Altitude of 0.5° Beam (km)	n	Percent with Signature
0.05 – 0.199	32	25.0%
0.2 – 0.399	84	27.4%
0.4 – 0.749	132	26.5%
0.75 – 0.99	89	**12.4%**
1 – 1.49	157	**12.1%**
1.5 – 1.99	112	**11.6%**
2 – 2.99	131	8.4%
3 – 3.99	34	2.9%
4+	9	0.0%

Table 5: Percentage of tornadoes intersected at various altitudes by the 0.5-deg beam with a debris signature.

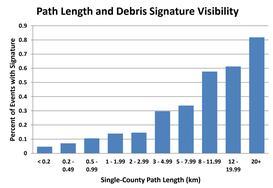


Fig. 5: Percentage of tornadoes in several single-county path length categories with debris signature.

Debris Signature Example: Moore, Oklahoma, EF-5 Tornado (20 May 2013)

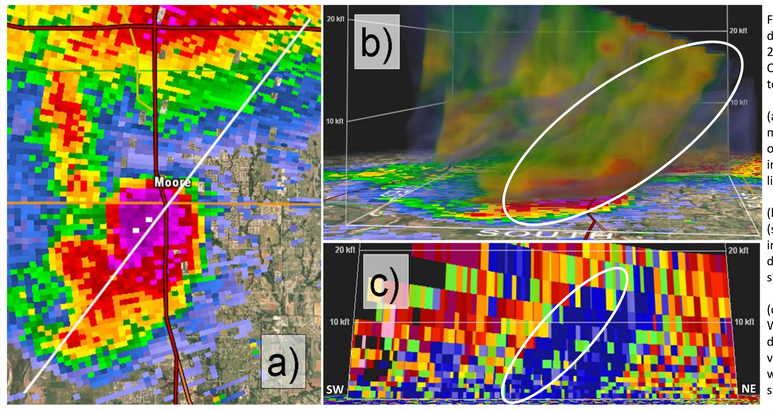


Fig. 6: Visualization of debris from the 20 May 2013 Moore, Oklahoma, EF-5 tornado:

(a): Z_{hh} debris manifestation. Location of cross-section in (c) is indicated by the white line.

(b): Z_{hh} isosurfaces (seen from the south) indicating lofted debris; white oval shows debris plume.

(c): ρ_{hv} cross-section. White oval indicates debris; other low values correspond to weak return south of supercell forward flank.

Case 1: A False 'Debris Ball' (KMQT, 9 June 2012)

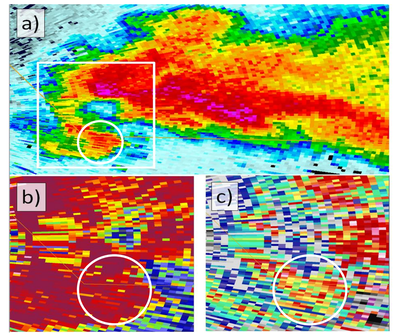
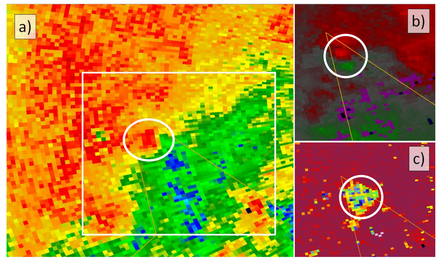


Fig. 7: Radar observations from the Marquette, MI, WSR-88D (KMQT) during a long-lived tornado event on 9 June 2012. (a): Z_{hh}, with white box showing the location of panels (b) and (c). (b) shows ρ_{hv}, and (c) shows Z_{DR}. A debris signature was visible during part of the tornado's life, but *not* at this time even though the parent supercell appears to have a 'debris ball' appearance in Z_{hh} (white circle in all panels).

Case 2: A Debris Signature over Water (KMHX, 30 May 2012)

Fig. 8: Radar observations from the Morehead City, NC, WSR-88D (KMHX) during a short-lived tornado on 20 May 2012. (a) shows Z_{hh}, with white box indicating the location of panels (b) and (c). (b) shows radial velocity, and (c) shows ρ_{hv}. A debris signature was readily apparent within the white-circled region, despite the tornado having been mostly over water.



Conclusions and Future Work

Conclusions

- Tornado debris signatures are most commonly observed in the Southern Plains and Southeast
- Signatures are increasingly prevalent as tornado intensity increases, with a majority of EF-2+ events containing a signature
- Debris signature occurrence is strongly dependent on distance from the radar; events intersected below 0.75 km are much more likely to be associated with a debris signature (corresponding to a range of ~60 km)
- Debris is most commonly observed in spring (likely due to a higher occurrence of strong tornadoes) and fall (possibly due to greater natural debris availability); debris also appears most rapidly after tornadogenesis in fall
- Areal extent of the debris signature is indicative of property damage, but not strongly indicative of EF-Scale
- Debris signatures may be visible in unusual cases—any strong vortex may loft debris to radar beam altitude

Future Work

- Signature comparison to underlying landcover
- Signature temporal characteristics relative to reported tornado lifetimes
- Examination of typical Z_{DR}, Z_{hh}, and ρ_{hv} values in events with different characteristics
- Analysis of signature vertical characteristics

Acknowledgements

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References

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