MES.P21

An Automated Method for Polarimetric Tornado Debris Detection

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Introduction

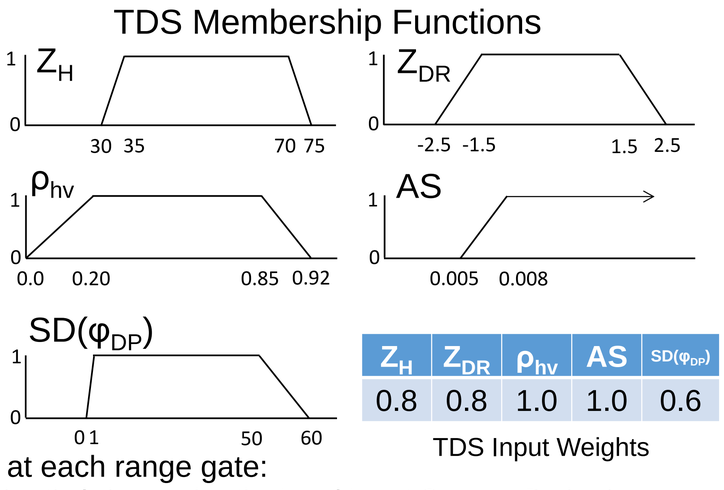
Although Doppler weather radars can detect some tornadoes (particularly those near the radar where resolution is best), many tornadoes still are not adequately observed in radial velocity (V_R) owing to a large beam height or a multitude of other factors. In addition, it can be difficult to determine which mesocyclones observed on radar are associated with tornadoes. The use of polarimetric radars has allowed for the characterization of debris lofted by tornadoes; the tornado debris signature (TDS; Ryzhkov et al. 2005) *provides what is nearly "ground truth" that a tornado is ongoing* (or recently was ongoing). This project outlines the modification of the hydrometeor classification algorithm (HCA) described by Park et al. (2008), a variant of which is used with the WSR-88D network in the United States, to include a TDS category for the purpose of identifying TDS events and reducing false classification where the TDS occurs.

TDS Characteristics and Algorithm Description

In the cases examined in Ryzhkov et al. (2005), Bluestein et al. (2007a,b), Kumjian and Ryzhkov (2008), Snyder et al. (2010), Schultz et al. (2012), Bodine et al. (2013), and Snyder and Bluestein (2014), amongst others, tornado debris sampled by polarimetric radars typically was characterized by low copolar cross-correlation coefficient (ρ_{hv}), low differential reflectivity (Z_{DR}), and moderate to high radar reflectivity factor at horizontal polarization (Z_H) co-located with a vortex signature in V_R. The existing version of the HCA used in the WSR-88D network tends to classify TDS events as either "RH" (rain mixed with hail) or as "UK" (unknown), the latter owing to the low aggregation value of all classes for the TDS events.

TDS Membership Functions

HCA Inputs
Z_H
Z_{DR}
ρ_{hv}
AS
$Log_{10}(K_{DP})$
$SD(Z_H)$
$SD(\varphi_{DP})$



Z_H	Z_{DR}	ρ_{hv}	AS	$SD(\varphi_{DP})$
0.8	0.8	1.0	1.0	0.6

TDS Input Weights

HCA Outputs
TDS
Light/Mod. Rain (L/MR)
Heavy Rain (HR)
Rain/Hail (R/Ha)
Big Drops (BD)
Anomal. Prop. (AP)
Unknown (UK)
Biological (BI)
Dry Snow (DS)
Wet Snow (WS)
Ice Crystals (CR)
Graupel (GR)

HCA process at each range gate:

1. Calculate azimuthal shear using the Local Least-Squares Derivative (LLSD) method (Smith and Elmore 2004)
2. Filter the AS field by determining the 95% percentile value of valid AS in a 4 radial x 8 range gate neighborhood around each gate.
3. Use fuzzy logic to determine the aggregation values for each output class
4. Select the output class with the highest aggregation value; disallow output class if aggregation value < 0.40
5. Enforce a series of strict rules (below) to reduce false classifications
6. Filter the output through a 5x5 mode filter centered on each range gate

Strict rules for TDS classification:

1. Radar beam must be below the melting layer
2. $\rho_{hv} \leq 0.92$
3. $Z_H \geq 25$ dBZ
4. $AS \geq 0.005\ s^{-1}$

Unlike the existing HCA, the modified HCA outputs the aggregation value for the selected class at each gate. This acts as a *measure of confidence* (i.e., fit to the membership functions) for given TDS identification.

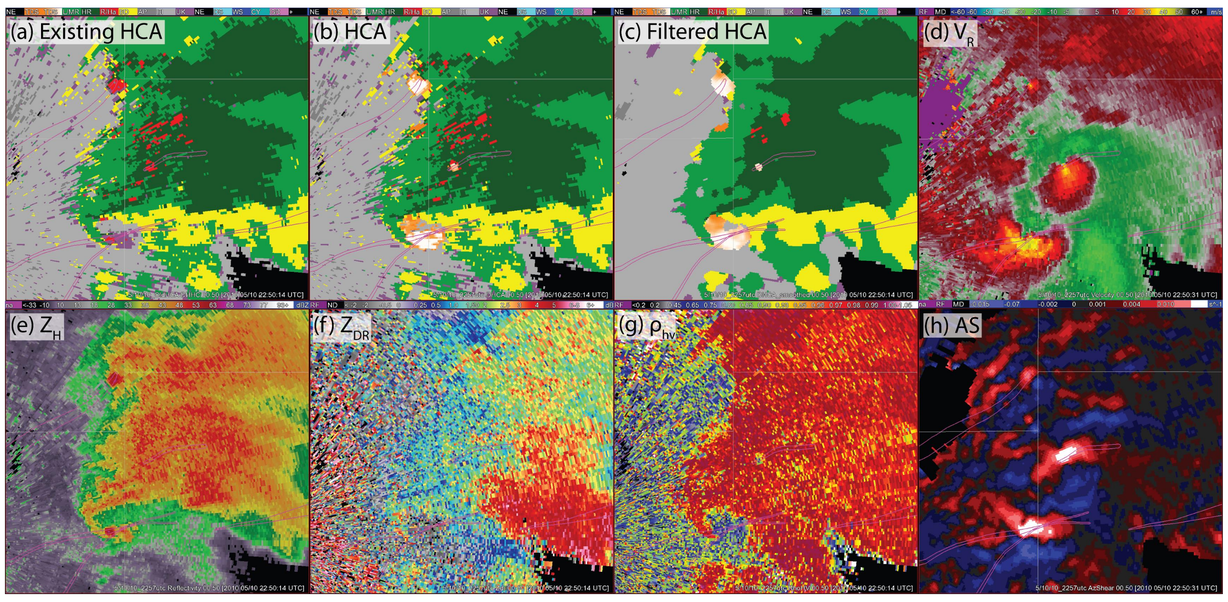
Select WSR-88D Characteristics	
Wavelength	S-band (~11 cm)
Range Resolution	250 m
Beamwidth (effective)	0.95 degrees (~1.3 degrees)
Azimuthal sampling rate	0.5 degrees
Elevation Angles	0.50 – 19.5 degrees
Transmit Power	750,000 W

All images presented herein were created in WDSS-II (Lakshmanan et al. 2007). Gates for which the TDS output is selected are shown in colors between orange (aggregation value < 0.75) to white (aggregation value of 1.0).

TDS Aggregation Value

0.4 "Less Confidence" — 0.75 — 1.0 "More Confidence"

TDS L/MR HR R/Ha BD AP BI UK NE DS WS CY GR



Above: (a) Existing HCA output, (b) modified HCA output, (c) filtered modified HCA output, (d) V_R, (e) Z_H, (f) Z_{DR}, (g) ρ_{hv}, and (h) AS from 2250 UTC on 10 May 2010 from KOUN as tornadoes were occurring across central Oklahoma. The magenta polygons denote tornado paths from damage assessments performed by the Norman, OK, National Weather Service Forecast Office (NWSFO). Four tornadoes were ongoing at this time.

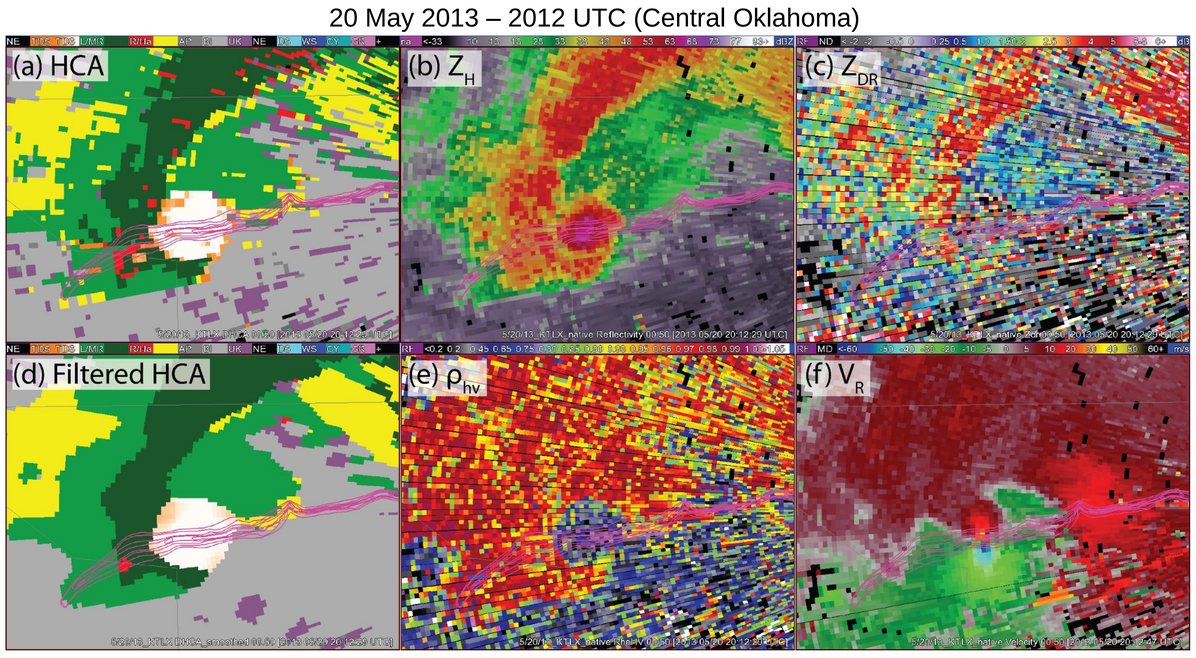
Challenges and Limitations of Automated TDS Detection

Given the potential importance of the TDS as a pseudo-"ground truth" indicator of a tornado, it is important to minimize false alarms. The following list contains some of the challenges to identifying TDS events that tend to result in misclassified radar gates:

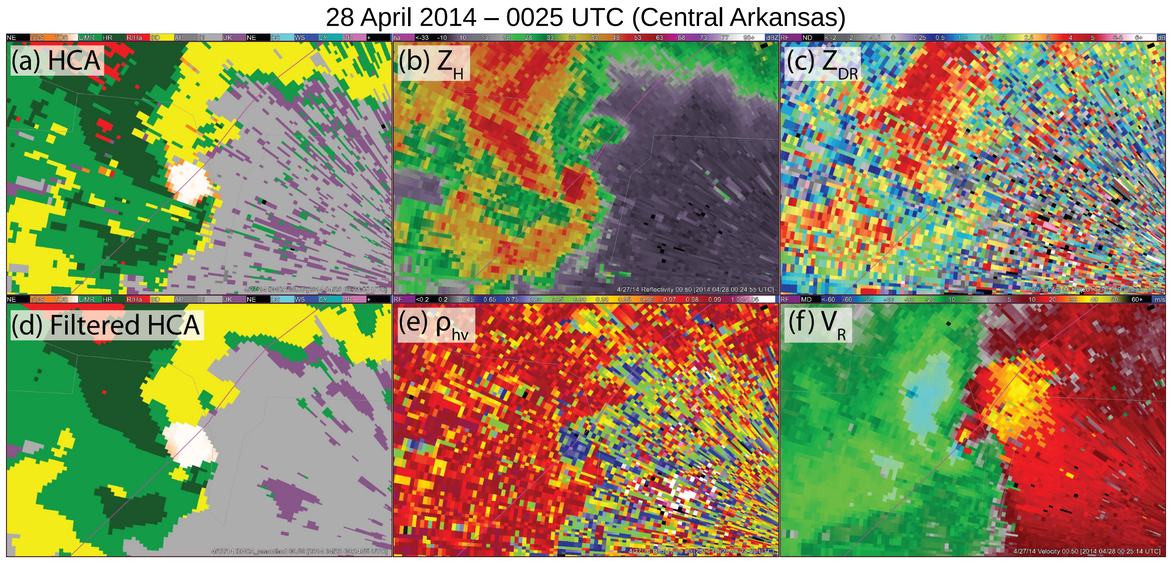
1. **Non-uniform beam filling (NBF)** – NBF is often manifests as a radially-oriented, significant reduction in ρ_{hv}, which can be extremely detrimental to TDS classification given the discriminating power of ρ_{hv}.
2. **Melting layer** – To mitigate problems with low ρ_{hv} near the melting layer, the TDS category is only allowed for gates at which the entirety of the beam is determined to be below the freezing layer. *This requirement places a limit on the distance from the radar at which a TDS can be detected*.
3. Near-radar clutter and data quality issues – The most common area for TDS misclassification is within ~20 km of the radar when echoes from convective storms "overlap" with ground clutter.
4. Debris fallout – After tornadoes dissipate, lofted debris, based upon anecdotal evidence and observations, may remain in the air for at least 5-10 minutes. If AS weakens significantly after dissipation, the settling debris will not be classified as such since the AS threshold may not be met.
5. Strong gust fronts – Strong AS, low ρ_{hv} , and relatively low Z_H are not uncommon near strong gust fronts associated with convective storms; such areas may be misidentified as a TDS since the parameter space of such events can overlap with that of tornado debris. To reduce misclassification, a strict lower limit of Z_H = 25 dBZ is enforced for a TDS classification.

TDS Detection Examples and Comparison with Tornado Tracks

20 May 2013 – 2012 UTC (Central Oklahoma)

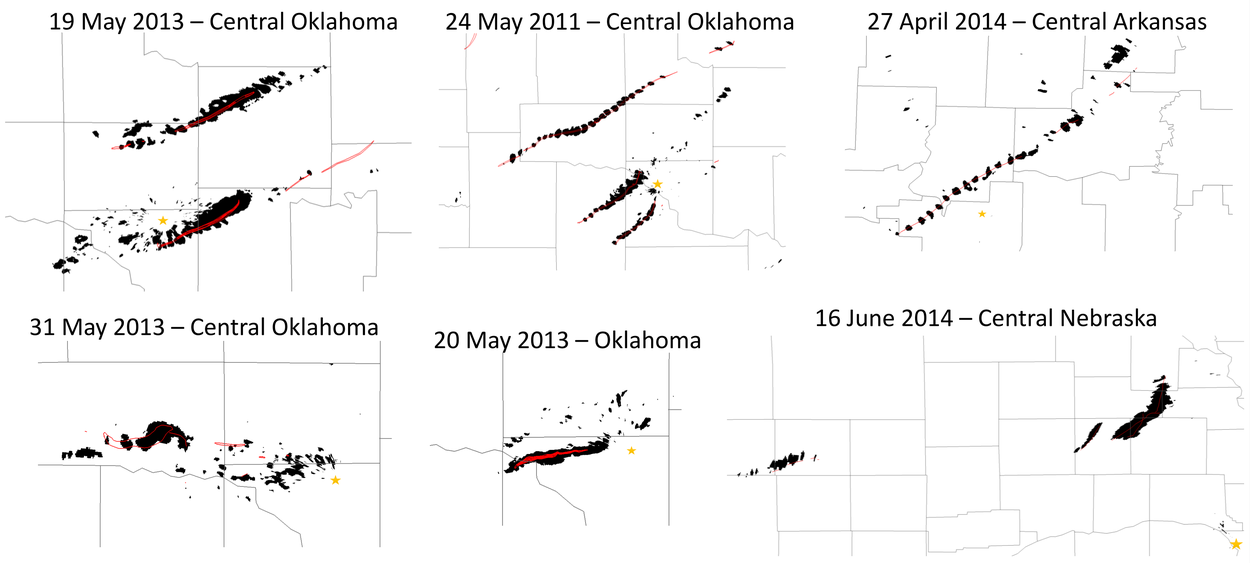


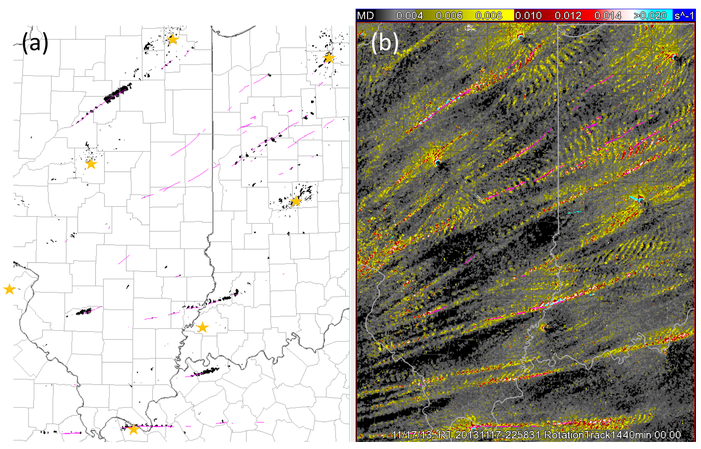
28 April 2014 – 0025 UTC (Central Arkansas)



TDS "Swaths"

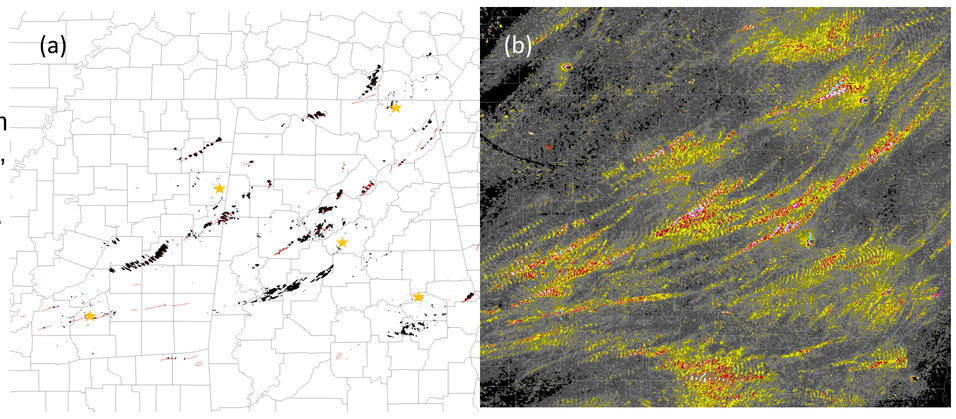
The images below represent the accumulated tracks of all TDS classifications from several notable tornadic events in the U.S.. Colored lines and polygons mark GIS-based tornado tracks as reported by the affected NWSFOs. Yellow stars denote the location of the WSR88D radars whose data are shown. TDS swaths, shown in black, represent all gates for which a valid the TDS class was assigned without any constraint on the aggregation value.





Left: (a) 17 November 2013 TDS swaths from a tornado outbreak that affected the Ohio Valley region of the U.S.. TDS data shown are from KLOT, KIND, KILX, KLSX, KIWX, KPAH, and KVWX. (b) Rotation tracks from NSSL OnDemand (http://ondemand.nssl.noaa.gov/) for this event. Several tornadoes did not produce an apparent TDS; several others did but were too far from the radar (i.e., the radar beam was too into the melting layer) for detection by the algorithm.

Right: (a) 28-29 April 2014 TDS swaths from KGWX, KDGX, KBMX, KHTX, and KMXX in the southeastern U.S.. (b) Rotation tracks as obtained from the NSSL OnDemand system for this event.



Ongoing Development

There remains a strong desire to minimize false classification of the TDS, and additional processing techniques to accomplish that end are being explored. Further adjustments to the membership functions, filtering methods, and other aspects of the algorithm will be made as we continue to analyze the characteristics of TDS events and the performance of the algorithm.

References

Available upon request.