Implementation of Tornadic Debris Signature Guidance Using Polarimetric WSR-88D Data

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Introduction

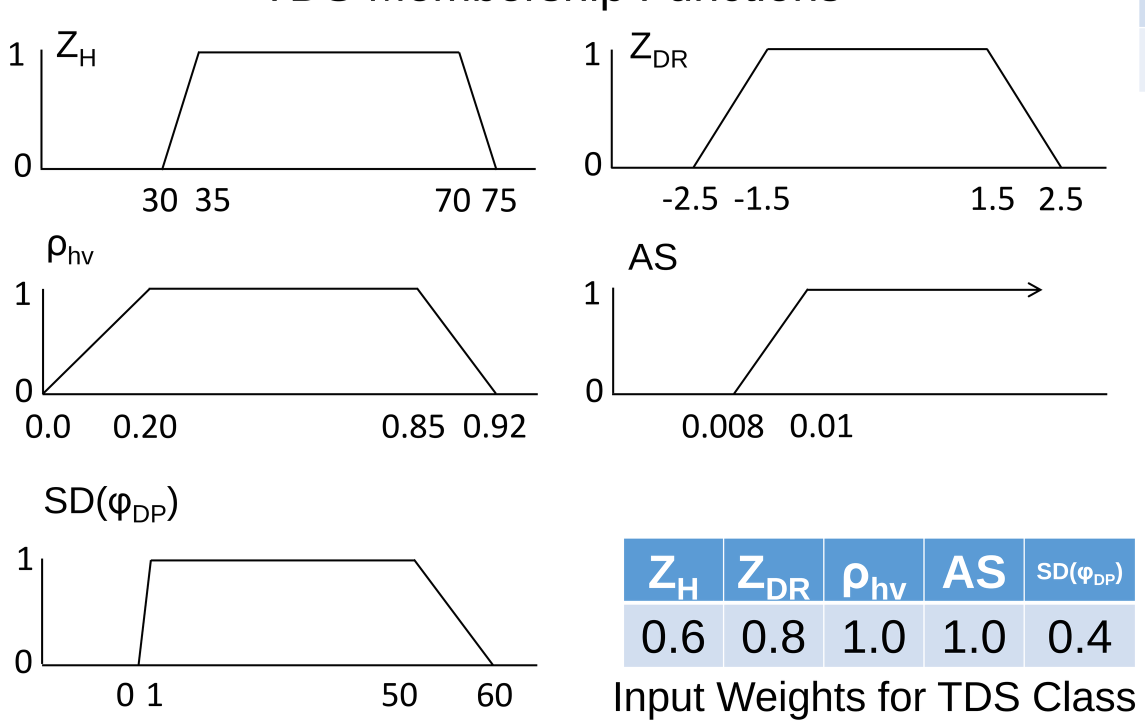
Although Doppler weather radars can detect some tornadoes (particularly those near the radar where resolution is best), many tornadoes still are not observed in radial velocity (V_R) owing to a large beam height and/or inadequate spatial and temporal resolution. In addition, it can be difficult to determine 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 polarimetric 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 & 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), Snyder and Bluestein (2014), and Kingfield et al. (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 "R/Ha" (rain mixed with hail) or as "UK" (unknown).

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)

TDS Membership Functions



Z_H	Z_{DR}	ρ_{hv}	AS	SD(φ_{DP})
0.6	0.8	1.0	1.0	0.4

Input Weights for TDS Class

HCA Inputs
Z_H
Z_{DR}
ρ_{hv}
AS
$\mathrm{Log}_{10}(K_{DP})$
SD(Z_H)
SD(φ_{DP})

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:

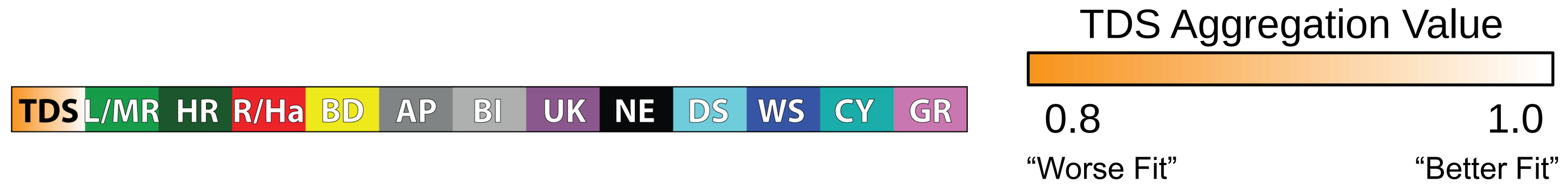
1. Center of radar beam must be below the melting layer
2. $\rho_{hv} \leq 0.92$
3. $Z_H \geq 25$ dBZ
4. AS $\geq 0.005\ s^{-1}$

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

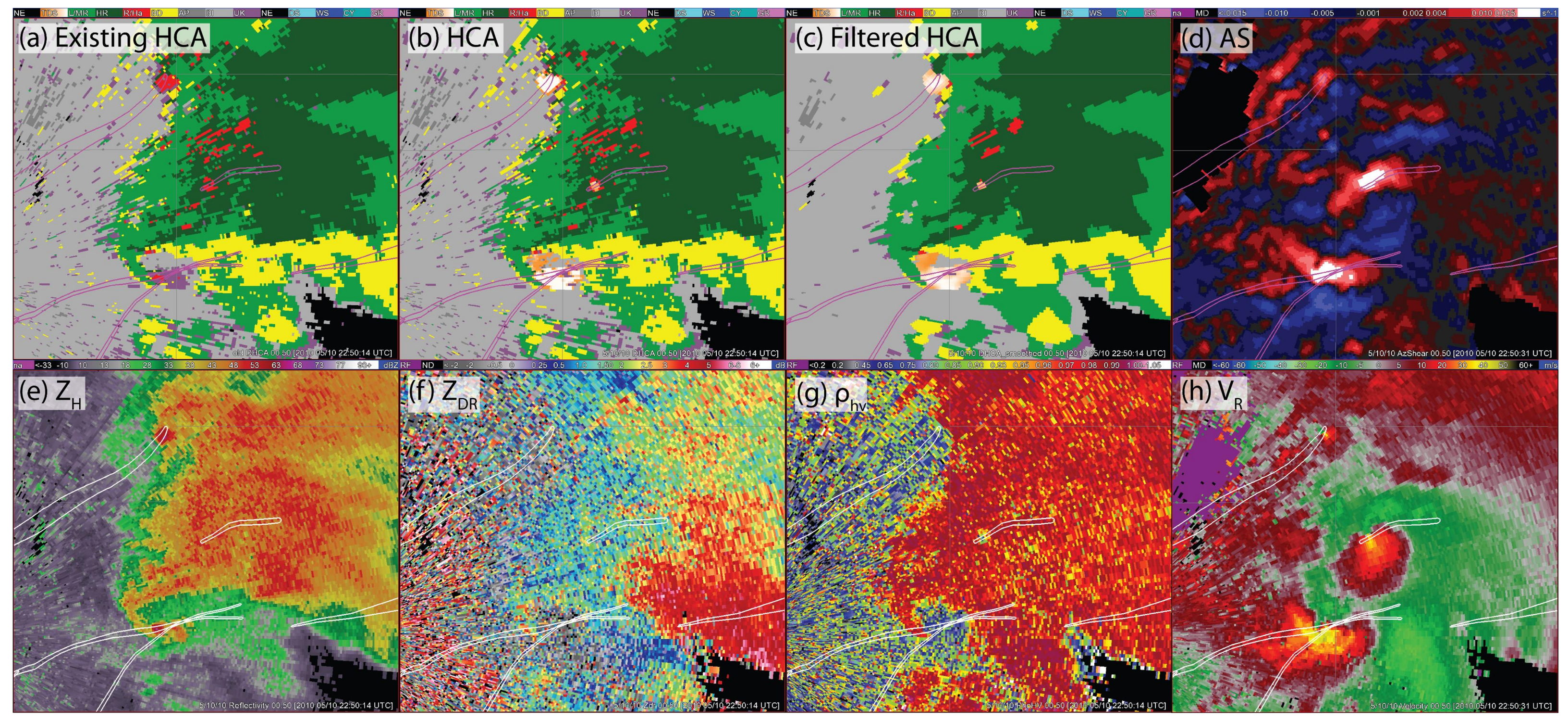
Select WSR-88D Characteristics	
Wavelength	S-band (~11 cm)
Range Resolution	250 m
Beamwidth (effective)	0.95 degrees (~1.3 degrees)
Azimuthal sampling rate	0.5-1.0 degrees
Elevation Angles	0.50° – 19.5°
Transmit Power	750,000 W

TDS Classification Examples

All images presented herein were created in WDSS-II (Lakshmanan et al. 2007). Gates for which the TDS class is selected are shown in colors between orange (aggregation value of 0.8) to white (aggregation value of 1.0).

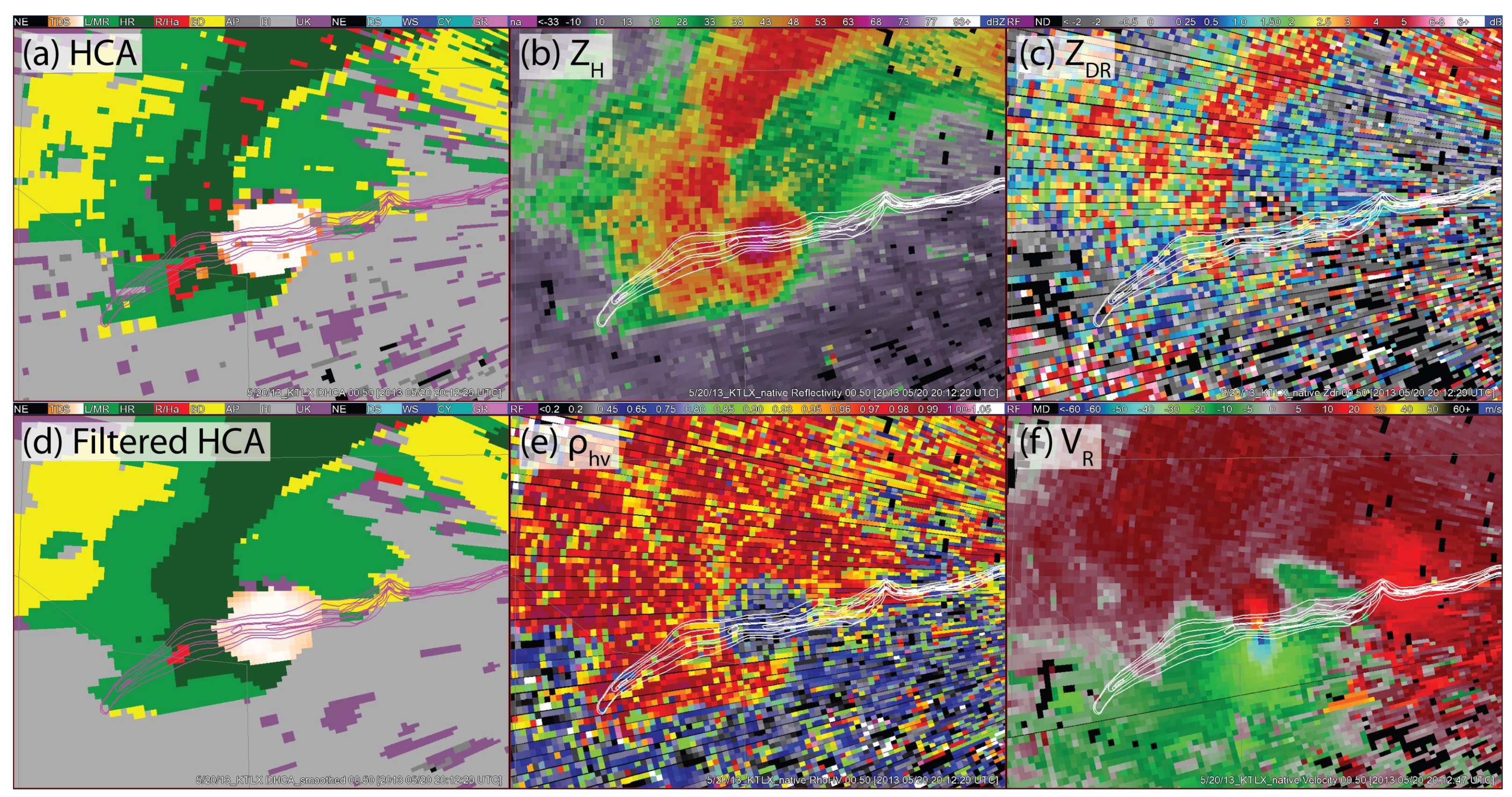


10 May 2010 – 2250 UTC (Central Oklahoma - KOUN)

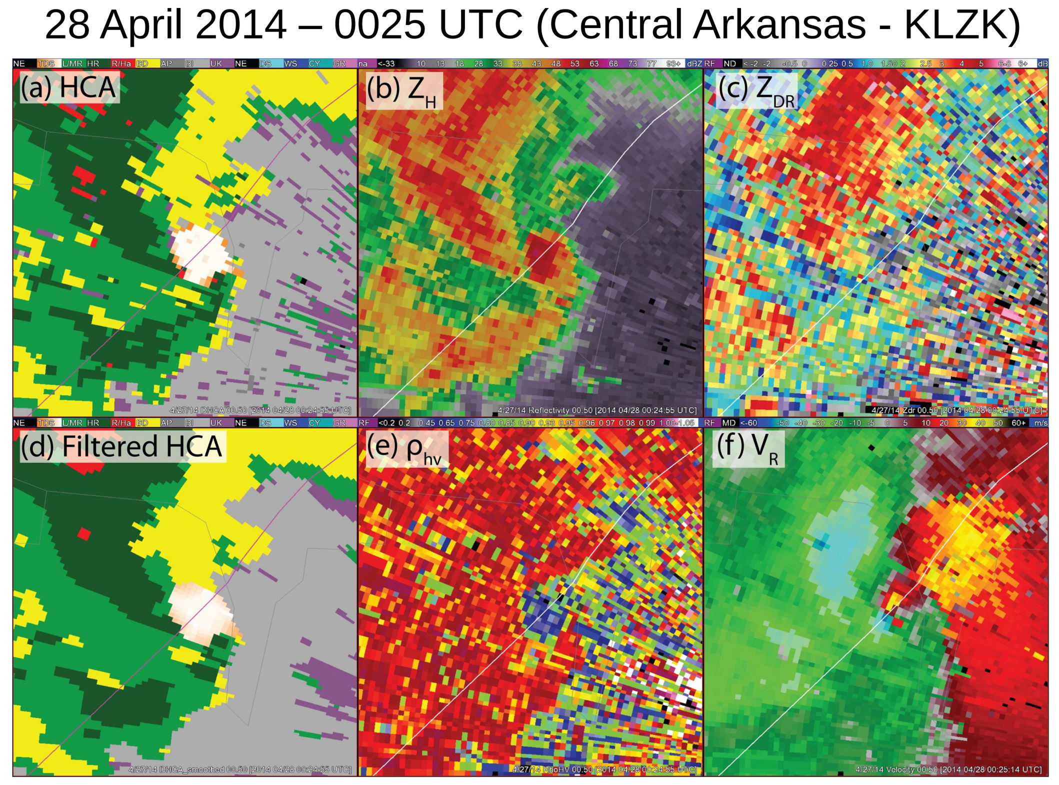


Above: (a) Existing HCA output, (b) modified HCA output, (c) filtered modified HCA output, (d) AS, (e) Z_H, (f) Z_{DR}, (g) ρ_{hv}, and (h) V_R valid 2250 UTC on 10 May 2010 from KOUN as tornadoes were occurring across central Oklahoma. The magenta polygons denote tornado paths from damage assessments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

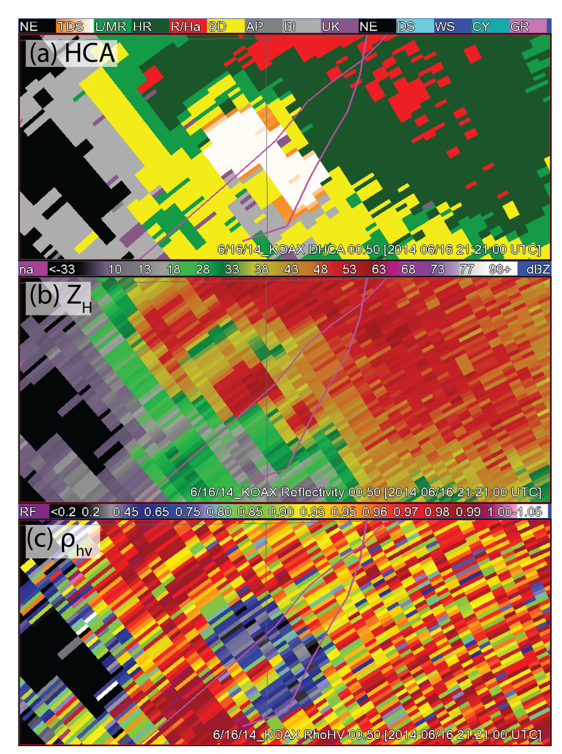
20 May 2013 – 2012 UTC (Central Oklahoma - KTLX)



28 April 2014 – 0025 UTC (Central Arkansas - KLZK)



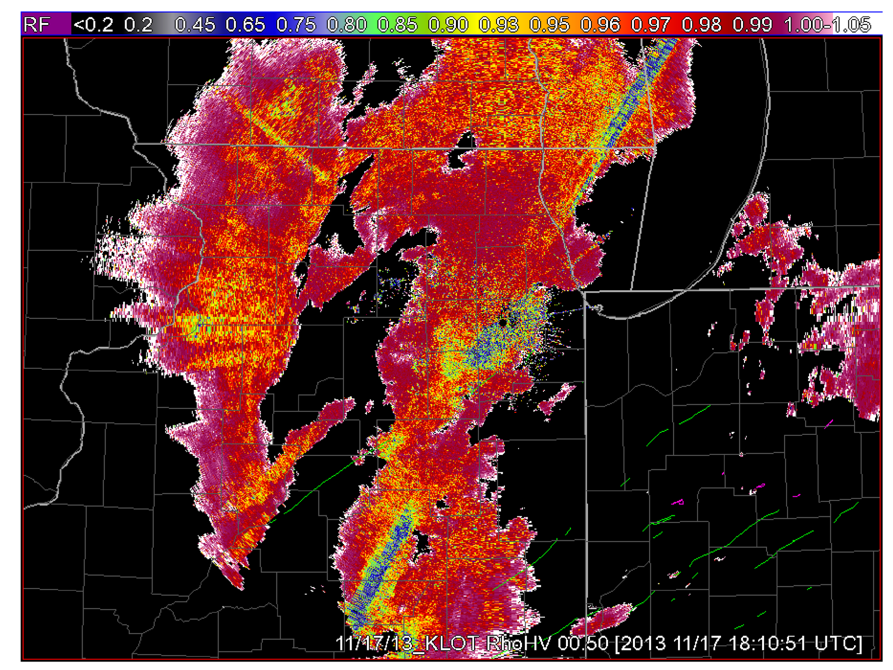
16 June 2014 – 2121 UTC (Eastern Nebraska - KOAX)



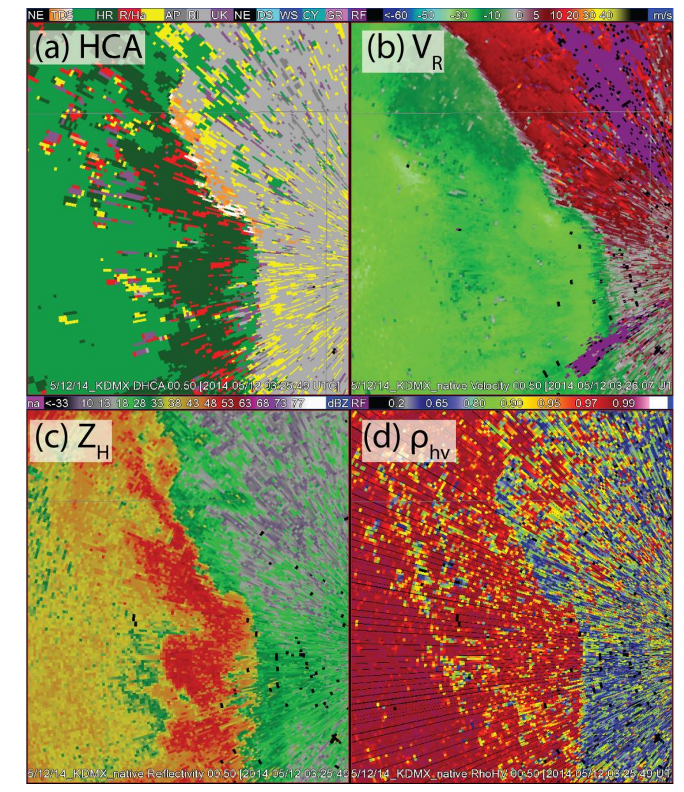
Challenges and Limitations of Automated TDS Detection

The following are common sources of TDS misclassification:

1. **Non-uniform beam filling (NBF)**
2. **Melting layer signature**
3. **Near-radar ground clutter / data quality**
4. **Strong gust fronts**



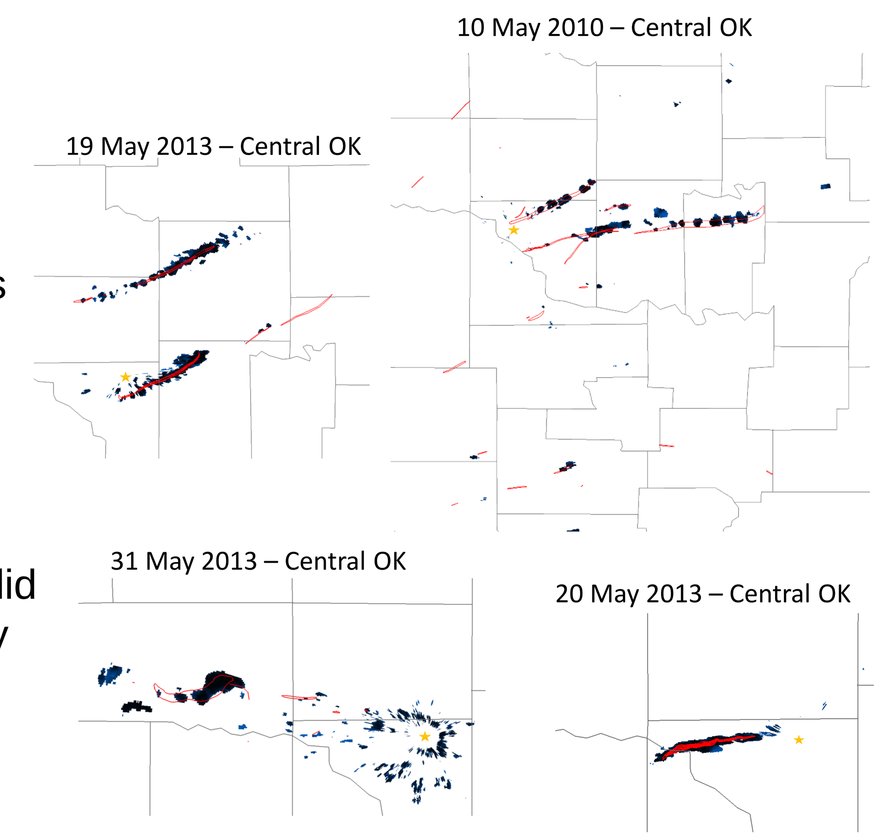
An example of NBF and the melting layer signature as seen in ρ_{hv}

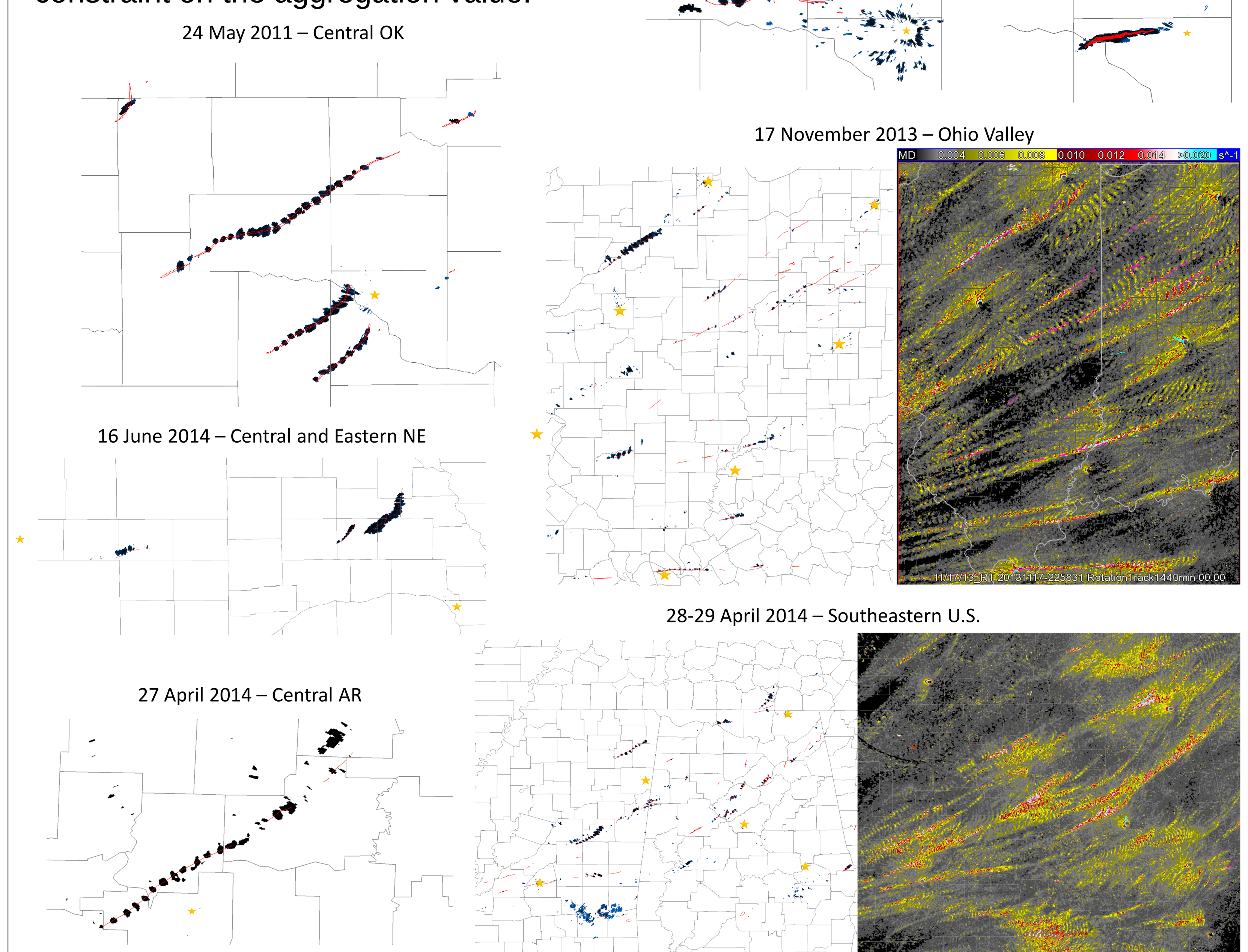


An example of ground clutter embedded within meteorological echoes and misclassification near a strong gust front

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 WSR-88D 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.





Rotation tracks obtained from the NSSL OnDemand system

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.