Fuzzy Logic Classification of Three-Body Scattering from S-band Polarimetric Radar Measurements

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Introduction

The three-body scatter signature (TBSS) is a radar artifact that appears downrange from a high radar reflectivity core in a thunderstorm. The TBSS occurs as a result of multiple (three-body) scattering of large hail when the radar-transmitted electromagnetic wave is scattered by hail to the ground, bounced back to the hail, and then scattered to the radar (Zrnic´ 1987). Since the TBSS is a radar artifact, identification is useful for quality control of radar data used in numerical weather prediction (NWP) and quantitative precipitation estimation (QPE). Therefore, it is advantageous to develop a method to identify the TBSS in radar data for operational use.

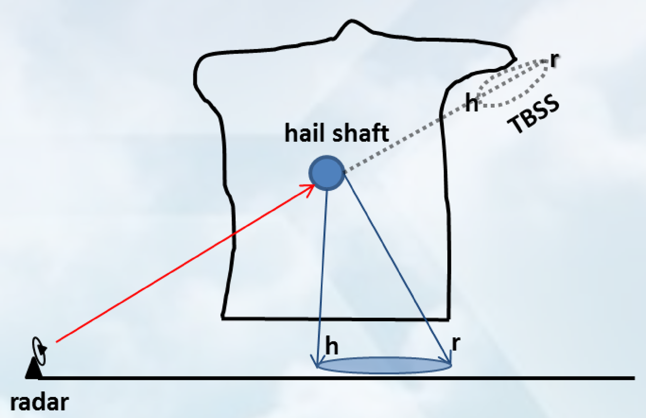

Figure 1. Schematic of the three-body scatter signature (TBSS).

Methodology

Polarimetric radar data collected by the dual-polarization KOUN Weather Surveillance Radar-1988 Doppler (WSR-88D) on 14 June 2011 were extracted to develop S-band trapezoidal membership functions for a TBSS class of radar echo.

- Five variables were investigated for the discrimination of the radar echo:
  1) horizontal radar reflectivity factor (ZH)
  2) differential reflectivity (Z_{DR})
  3) copolar cross-correlation coefficient (ρ_{hv})
  4) the standard deviation of horizontal radar reflectivity factor (SD[Z_H])
  5) the standard deviation of differential phase (SD[Φ_{DP}])
- Nearly 3000 radar gates were extracted from 50 TBSSs to statistically develop the membership functions
- Membership functions were added to a modified hydrometeor classification algorithm (HCA) based upon Park et al. (2009) to identify TBSSs
- Hard thresholds for the TBSS class were implemented into the algorithm
- Testing was conducted on radar data collected by dual-polarized WSR-88Ds from multiple severe weather events that were associated with TBSSs

Statistics of Radar Variables

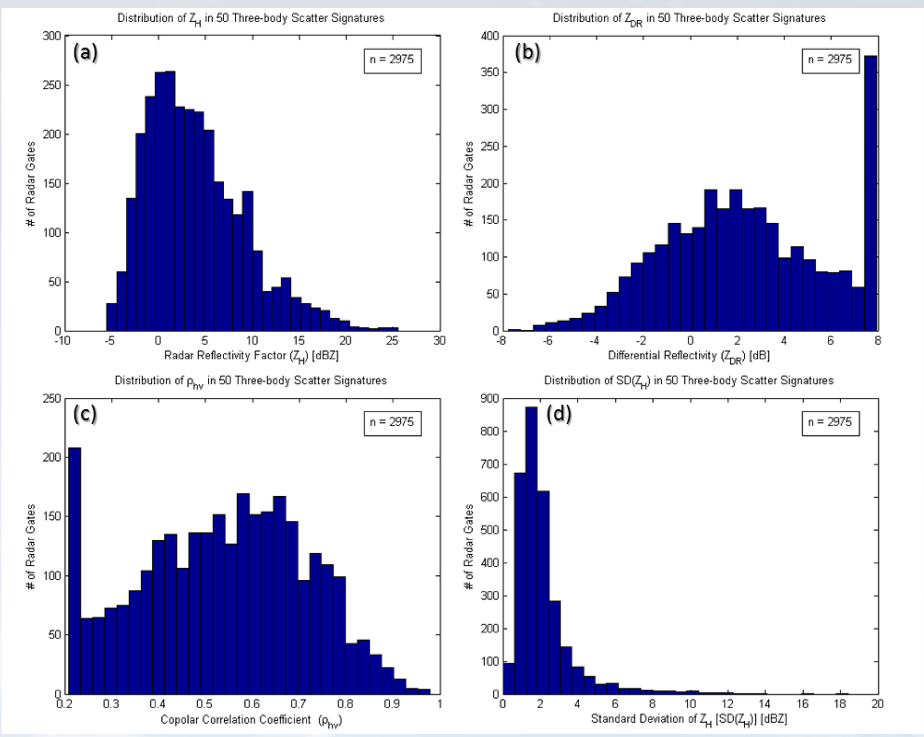

Figure 2. The distribution of (a) radar reflectivity factor (Z_H), (b) differential reflectivity (Z_{DR}), (c) copolar correlation coefficient (ρ_{hv}), and (d) the standard deviation of Z_H [SD(Z_H)] in 2975 radar gates from 50 three-body scatter signatures (TBSSs).

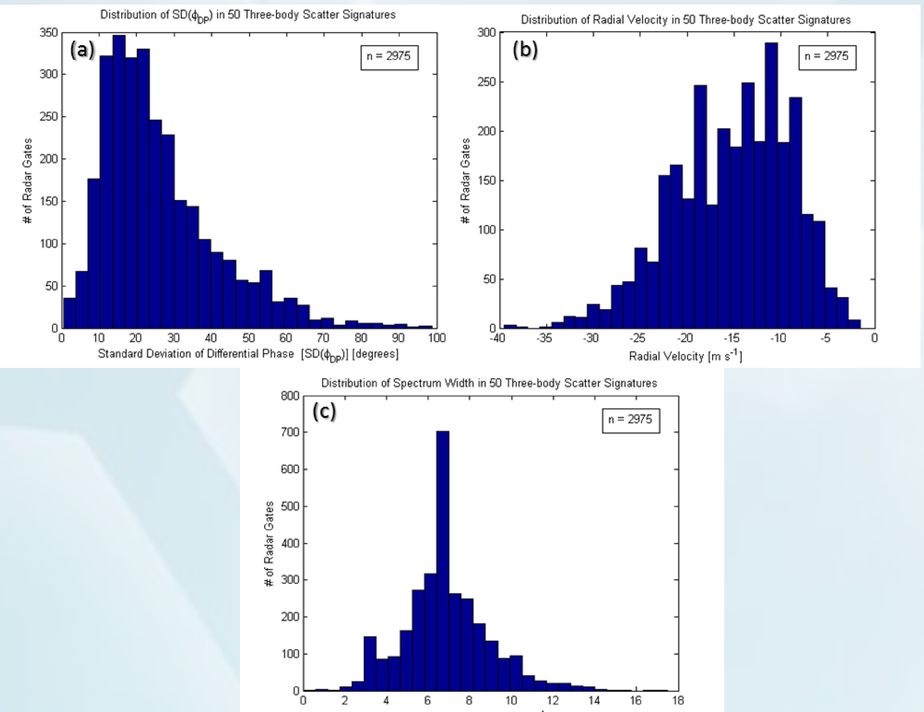

Figure 3. Same as Figure 2, but the distribution of (a) the standard deviation of differential phase [SD(Φ_{DP})], (b) measured radial velocity, and (c) spectrum width.

Modified HCA

For each radar gate, an aggregation value, A_i, for the ith class (i = 1, 2…11) of radar echoes is calculated. A_i is defined as (Park et al. 2009):

$$A_i = \frac{\sum_{j=1}^{5} W_{ij} P^{(i)}(V_j)}{\sum_{j=1}^{5} W_{ij}}$$

where $P^{(i)}(V_j)$ is the trapezoidal membership function for the j^{th} variable for the i^{th} class, and W_{ij} is a weight between 0 and 1 assigned to the i^{th} class and j^{th} variable. The classification of the radar echo is determined by which class has the largest aggregation value.

All the membership functions, weights, and hard thresholds were the same as Park et al. (2009) for the non-TBSS classes.

Confidence vectors were not used in this study.

Development of the S-band Membership Functions

As in Park et al. (2009), the membership functions were fit to trapezoidal functions. The following criteria from the collected data were used to determine the four parameters in the five trapezoidal membership functions:

- x_1: 0.5 percentile
- x_2: 20th percentile
- x_3: 80th percentile and
- x_4: 99.5th percentile

P(X) ranges from 0 to 1.

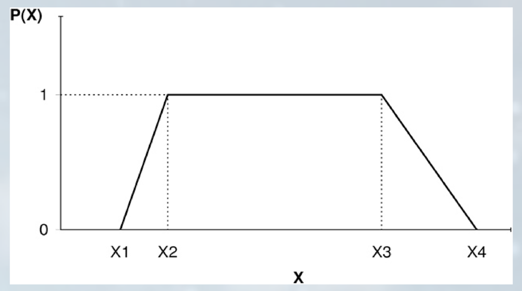

Figure 4. Trapezoidal membership function. [From Park et al. (2009)]

Weights were subjectively determined by comparing the derived parameters to the other 10 classes.

Table 1. Parameters of the trapezoidal S-band membership functions for the TBSS class.

	P[Z_H(dBZ)]	P[Z_{DR}(dB)]	P(ρ_{hv})	P[SD(Z_H)(dB)]	P[SD(Φ_{DP})(°)]
x_1	-5	-5.9	0.00	0	0
x_2	0	-2.2	0.28	1.0	10
x_3	10	8.0	0.77	3.5	50
x_4	25	12.0	0.92	11	90
Weight	1.0	0.2	1.0	1.0	0.2

Hard threshold checks if at least one radar gate with radar reflectivity ≥ 58 dBZ and at least one radar gate with a hail/rain classification is downrange at least 10 km (40 gates) from a possible TBSS classification. If not, checks if at least one radar gate with a TBSS classification is at least 2 km downrange.

Results

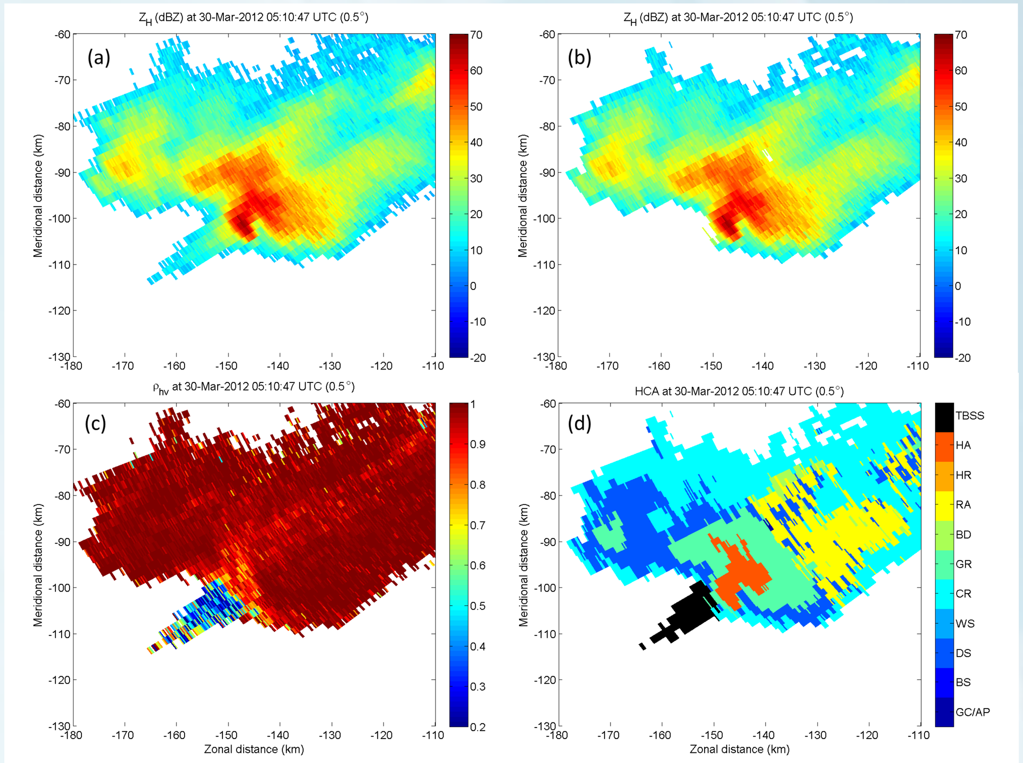

Figure 5. Example event from KVNX associated with 10.2 cm hail with (a) radar reflectivity, (b) quality-controlled radar reflectivity (removes GC/AP, BS, and TBSS), (c) correlation coefficient, and (d) hydrometeor classification. In panel (d), the classifications are: 1) ground clutter and anomalous propagation (GC/AP); 2) biological scatterers (BS); 3) dry aggregated snow (DS); 4) wet snow (WS); 5) crystals (CR); 6) graupel (GR); 7) big drops (BD); 8) light and moderate rain (RA); 9) heavy rain (HR); 10) a mixture of rain and hail (RH); and 11) three-body scatter signature (TBSS).

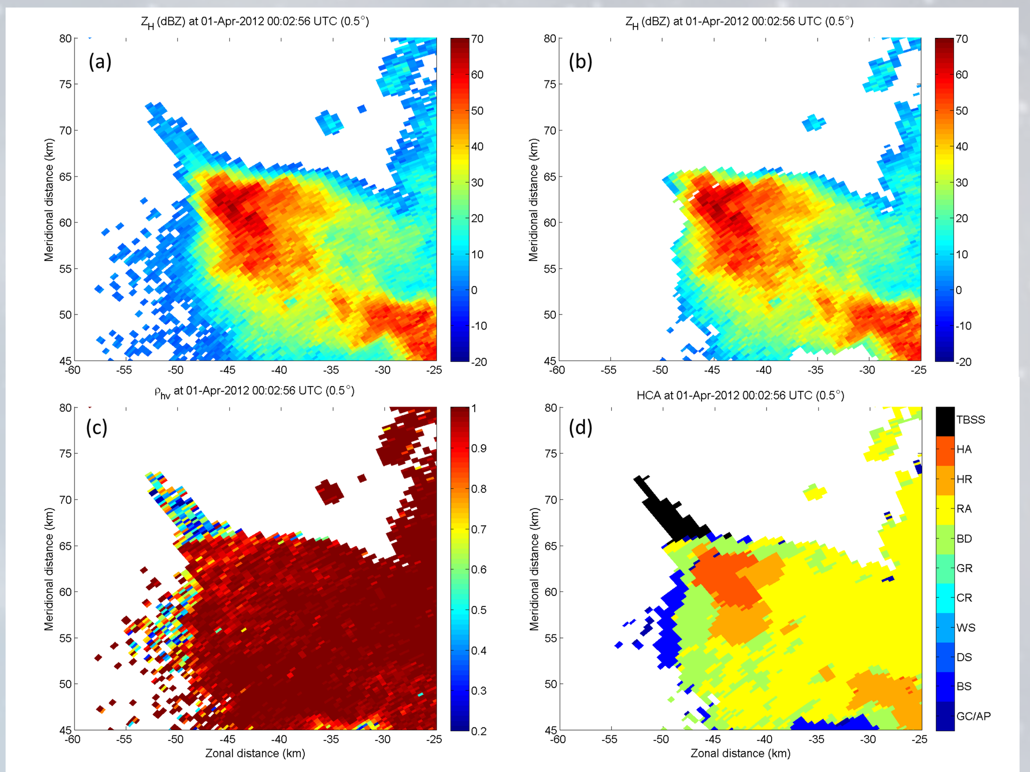

Figure 6. Example event from KBMX associated with 7.6 cm hail.

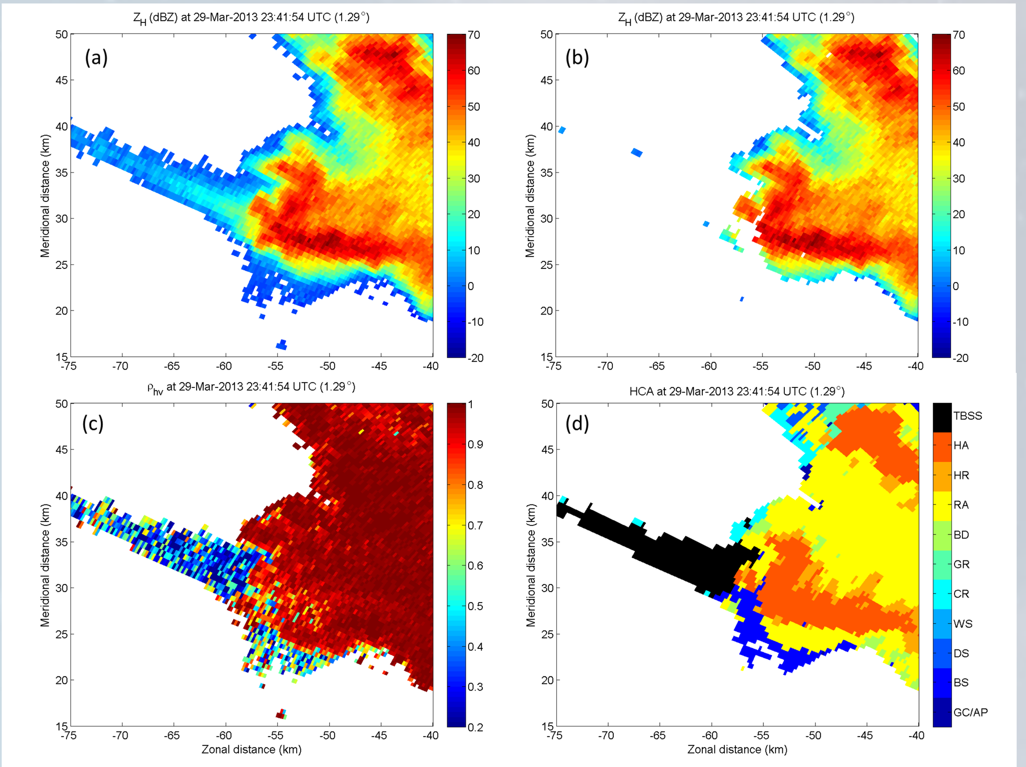

Figure 7. Example event from KTLX associated with 6.4 cm hail.

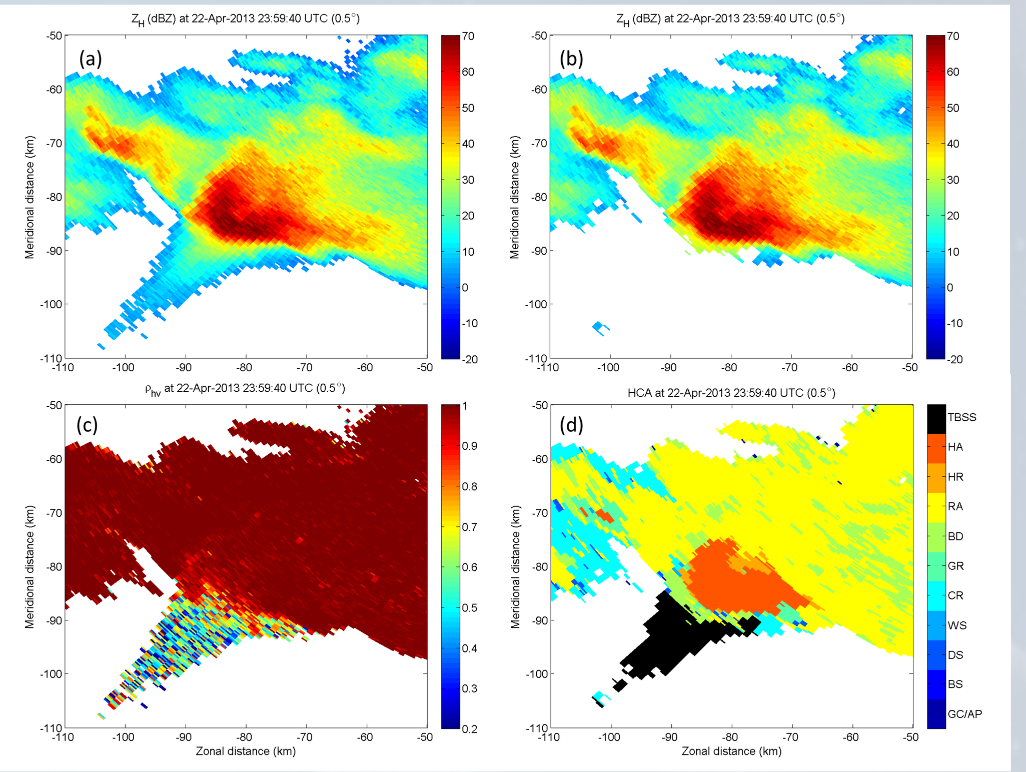

Figure 8. Example event from KICT associated with 5.1 cm hail.

References

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