Developing a Tornado Debris Signature Algorithm for Use in the WSR-88D Network

JEFF SNYDER

COOPERATIVE INSTITUTE FOR MESOSCALE METEOROLOGICAL STUDIES

THE UNIVERSITY OF OKLAHOMA, AND NOAA/OAR NATIONAL SEVERE STORMS LABORATORY

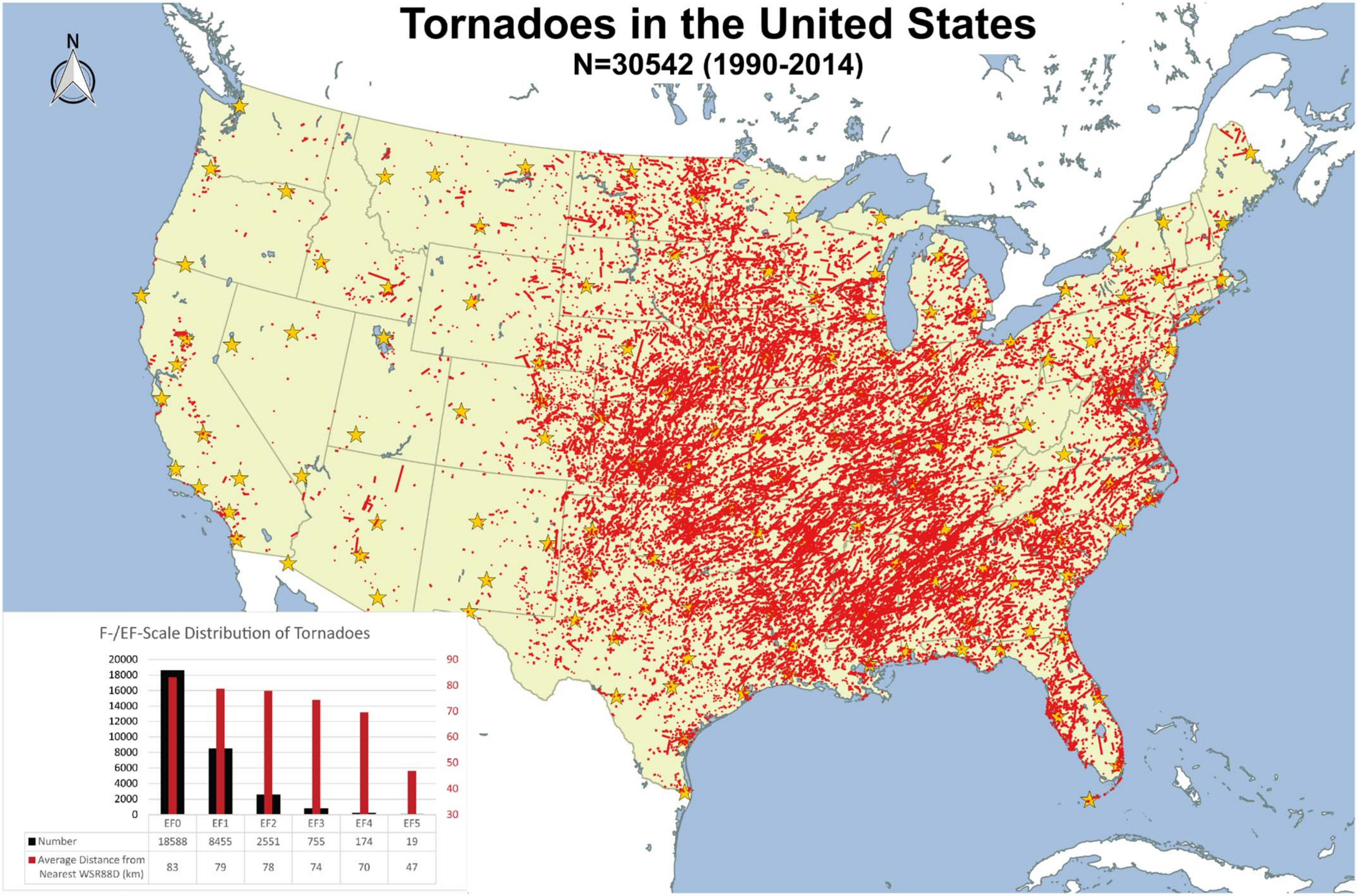
NORMAN, OK

Motivation

Polarimetric weather radar provides a vast quantity of information regarding scatterer properties

Resolution and beam height inadequacies tend to make tornado detection difficult with WSR88D radars if only V_R is used, particularly when not close to the radar

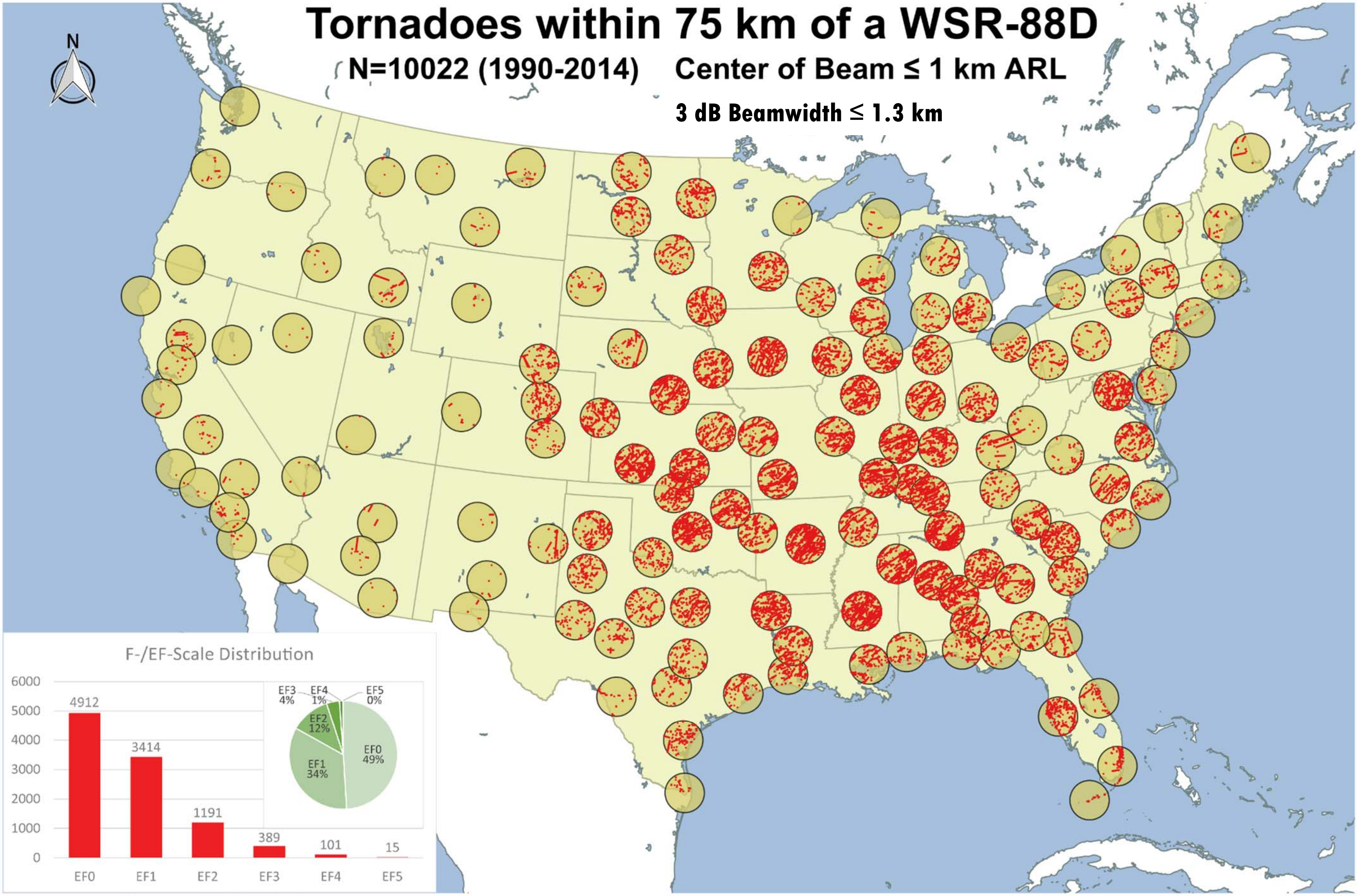
Detection of tornado debris provides as close as we can get to “ground truth” using only remote sensing data (important at night, in forested areas or elsewhere when/where real-time verification may be difficult)



Map created by Jeff Snyder
Jeffrey.Snyder@noaa.gov
10 September 2015

Tornado tracks from the SPC Severe Weather Database
(http://www.spc.noaa.gov/wcm/#data)

250 0 250 500 750 1000 km



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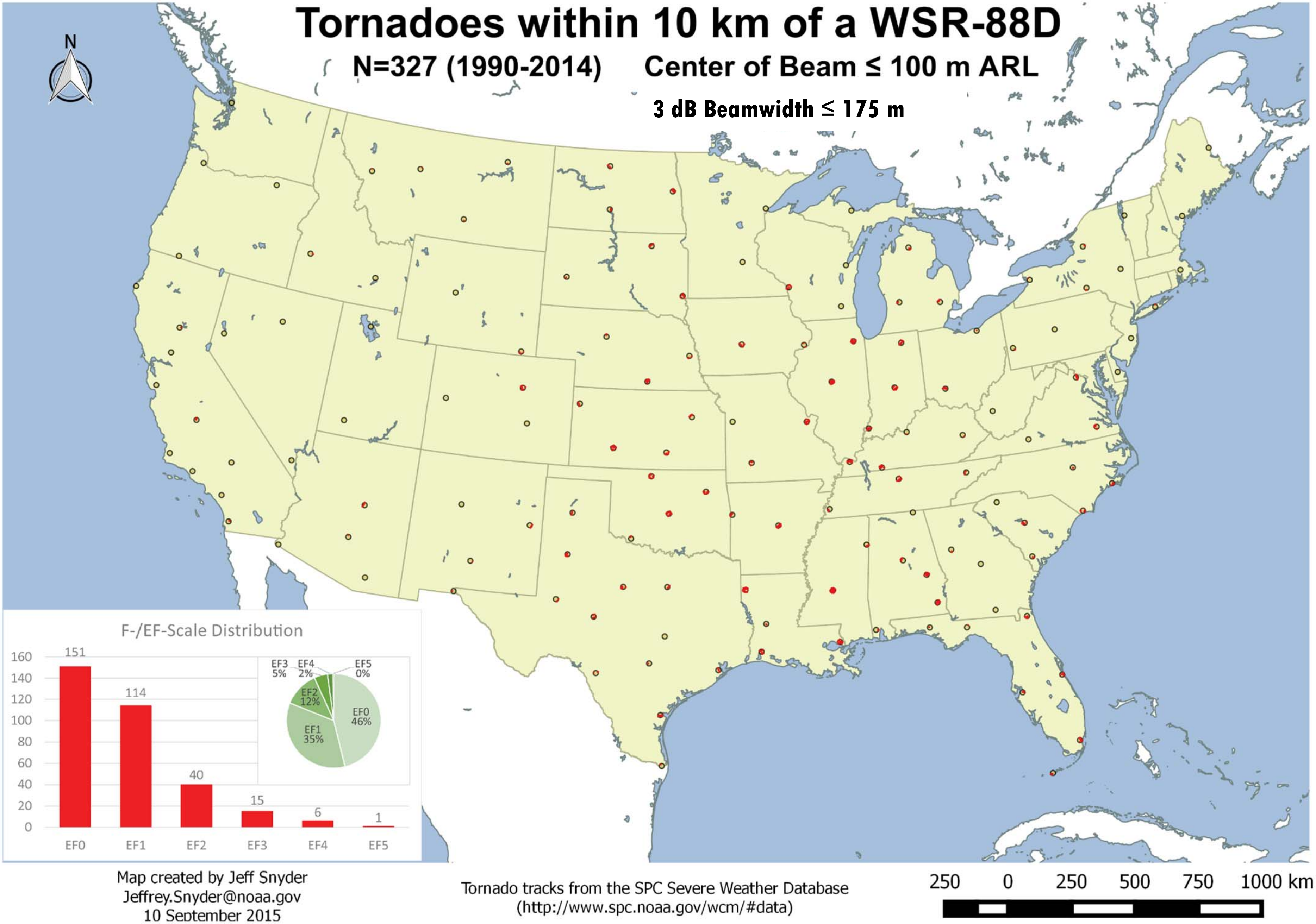

Tornadoes within 10 km of a WSR-88D
N=327 (1990-2014)
Center of Beam ≤ 100 m ARL
3 dB Beamwidth ≤ 175 m
N
F-/EF-Scale Distribution
160
140
120
100
80
60
40
20
0
151
114
40
15
6
1
EF0
EF1
EF2
EF3
EF4
EF5
EF3 5%
EF4 2%
EF5 0%
EF2 12%
EF1 35%
EF0 46%
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Tornado tracks from the SPC Severe Weather Database
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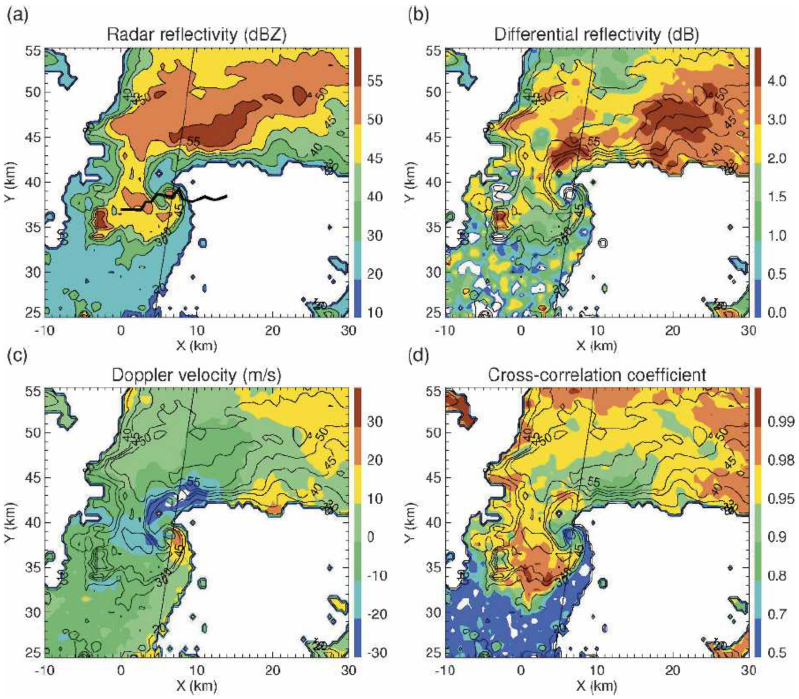
250 0 250 500 750 1000 km

Tornado Debris Detection

Polarimetric weather radar has a very good history of use in discriminating meteorological from non-meteorological scatterers

Observations of tornadoes by polarimetric radars on 3 May 1999 and subsequent events (Ryzhkov et al. 2005) led to the description of a set of characteristics common to debris from tornadoes

- Low ρ_{hv}
- Moderate to high ZH
- Low Z_{DR}
- Strong vortex couplet in V_R



From Ryzhkov et al. (2005)

How Common are TDSs?

The radar can only sample debris from a tornado if the tornado produces debris! Ergo, a TDS detection algorithm will not identify tornadoes that do not produce tornado (at the height of the radar beam)

Van den Broeke and Jauernic (2014) looked at 745 tornadoes and found that TDS occurrence:

- Increased with increasing tornado EF-scale rating
- Decreased with increasing range from the radar (reduced spatial resolution owing to beam broadening, increased beam height at lowest elevation angle, etc.)

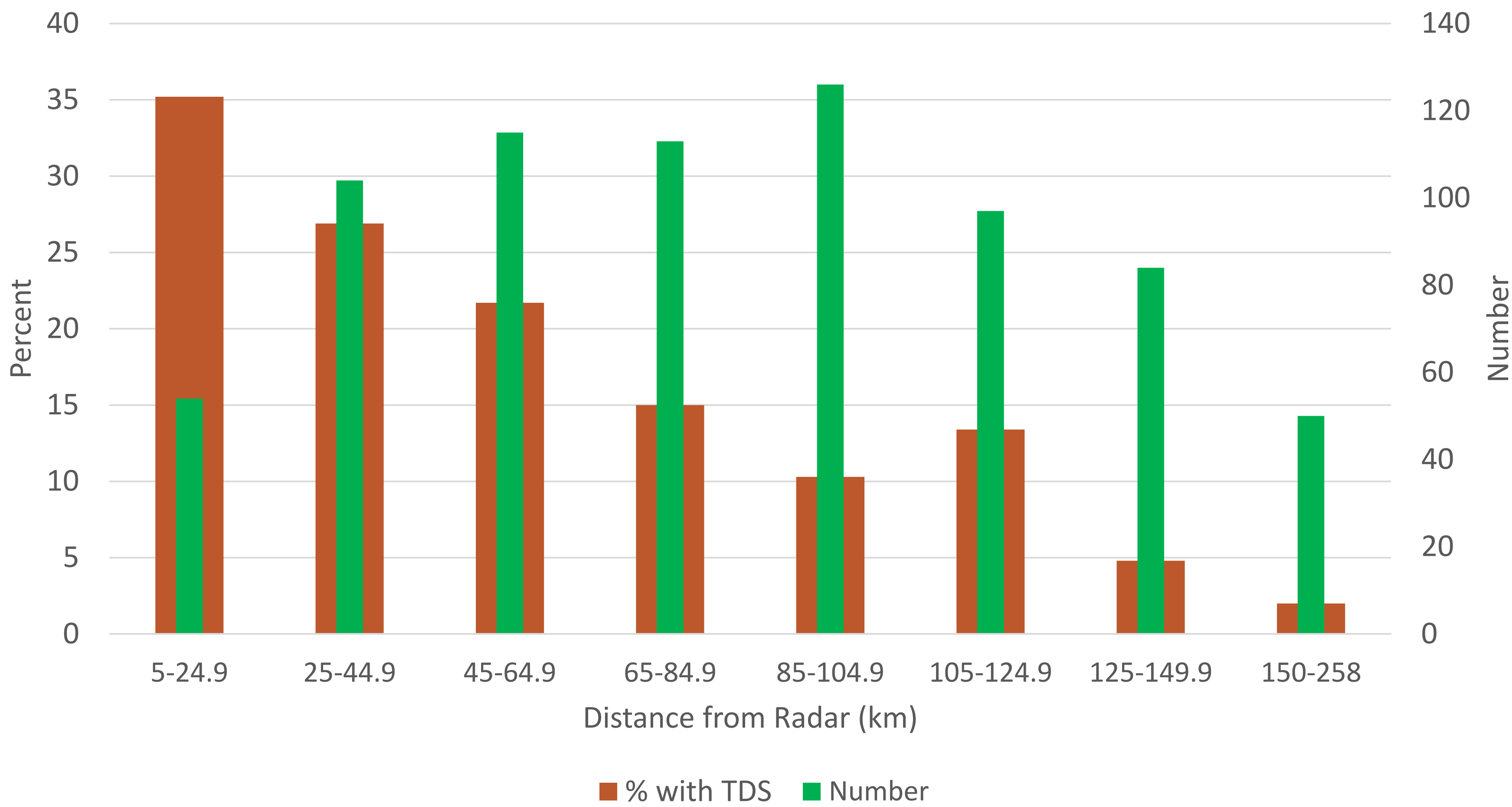
Overall, only ~16% of tornado examined were associated with a TDS

TABLE 2. Average longevity of tornadoes in each EF-scale classification, percentage of tornadoes in each rating classification exhibiting a TDS, and average TDS areal and vertical extents for all events with a signature.

Classification	n	Avg longevity (min)	% with signature	Avg areal extent (km^2)	Avg max vertical extent (km)
EF-0	437	3.2	6.2%	0.93	1.47
EF-1	227	7.1	18.9%	1.83	1.93
EF-2	57	10.2	49.1%	2.42	3.11
EF-3	17	31.1	88.2%	7.67	4.37
EF-4	6	32.2	100.0%	6.83	4.32
EF-5	1	31	100.0%	23.74	6.28+

TDS Occurrence with Range

Adapted from Van den Broeke and Jauernic (2014)



Existing WSR-88D HCA

HCA Inputs
Z_H
Z_{DR}
P_{hv}
$SD(\phi_{DP})$
$Log_{10}(K_{DP})$
$SD(Z_H)$
AS*

Based on fuzzy logic

- A series of membership functions are defined for each input type for each output class
- Different input weights allow some inputs to “count” more than others
- Weights and membership values are combined to determine the “most likely” or dominant source of scattering in a volume

Park et al. (2009)

* New additions

HCA Outputs
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*

TDS Detection

Multiple ways by which such a TDS "product" can be produced

- Threshold azimuthal shear / "rotation tracks" on polarimetric quantities
- Geospatial analysis vs. binary indication (e.g., icon similar to the TVS icon)
- *Modify hydrometeor classification algorithm (HCA) with a new "TDS" class

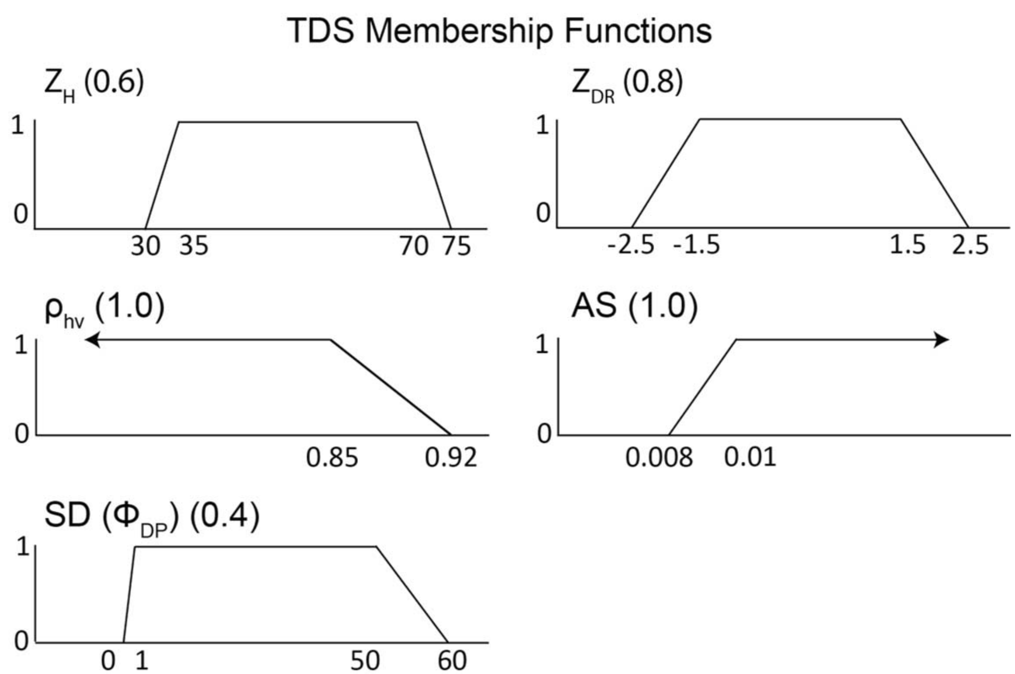
Currently, we know that HCA incorrectly classifies the TDS (usually "rain/hail" or "unknown")

We will focus on spatial classification of the TDS

Membership functions were created from characteristics in literature

Minimizing false detections is a priority!

See Snyder and Ryzhkov (2015) in *JAMC* for additional details



Modified HCA – Method

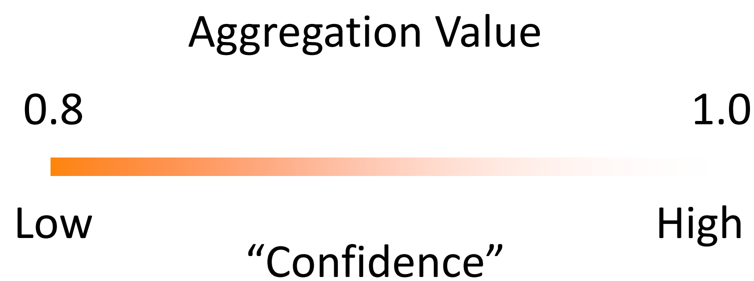
1. Calculate azimuthal shear using the Local Least-Squares Derivative (LLSD) method (Smith and Elmore 2004)
2. Filter the AS field by determining the 95% percentile value of valid AS in a 4 radial x 8 range gate neighborhood around each gate (this “smearing” essentially identifies neighborhoods around tornadoes, important because the TDS often encompasses areas outside the immediate vortex couplet)
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 for TDS to reduce false classifications
    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 $\geq 0.005\ s^{-1}$
    5. Aggregation value ≥ 0.8
6. Filter the output through a 2D mode filter to despeckle

TDS Classification – “Confidence”

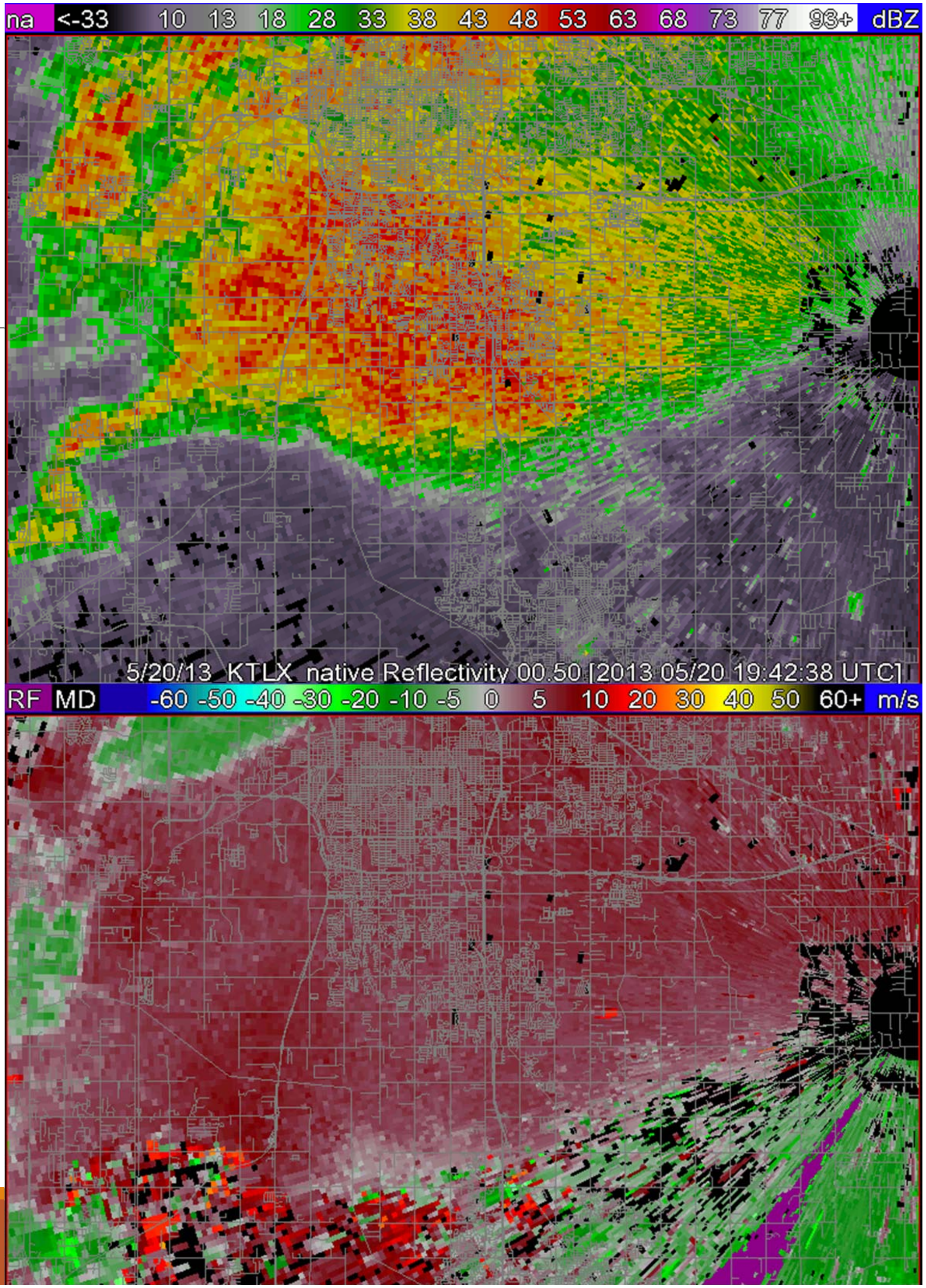
The fuzzy logic method lets one gauge how well a given set of observations “fit” the membership functions

New HCA provides aggregation value in addition to the selected class (almost always the output with the greatest aggregation value)

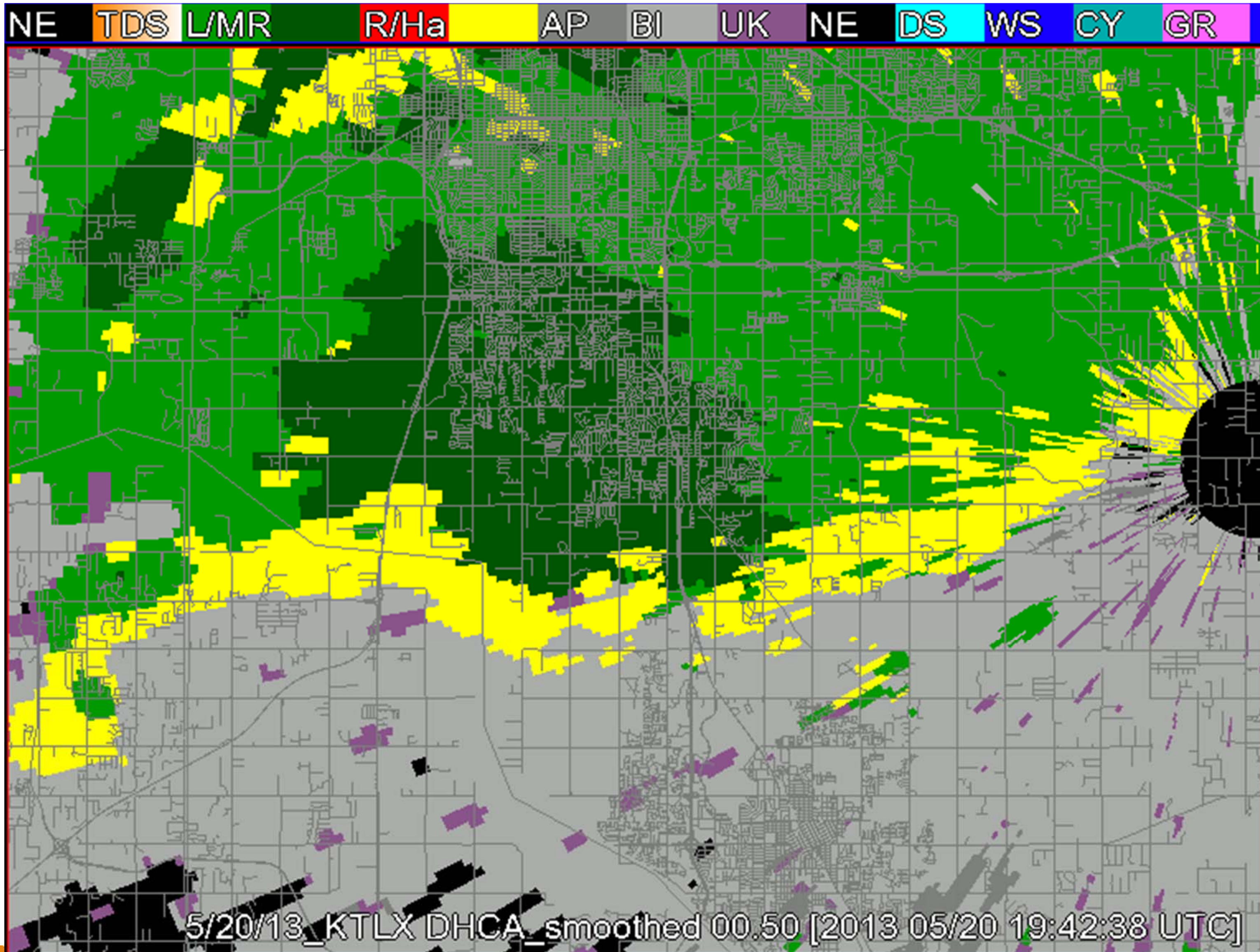
Allows the user to set custom “threshold” for display by choice of color table



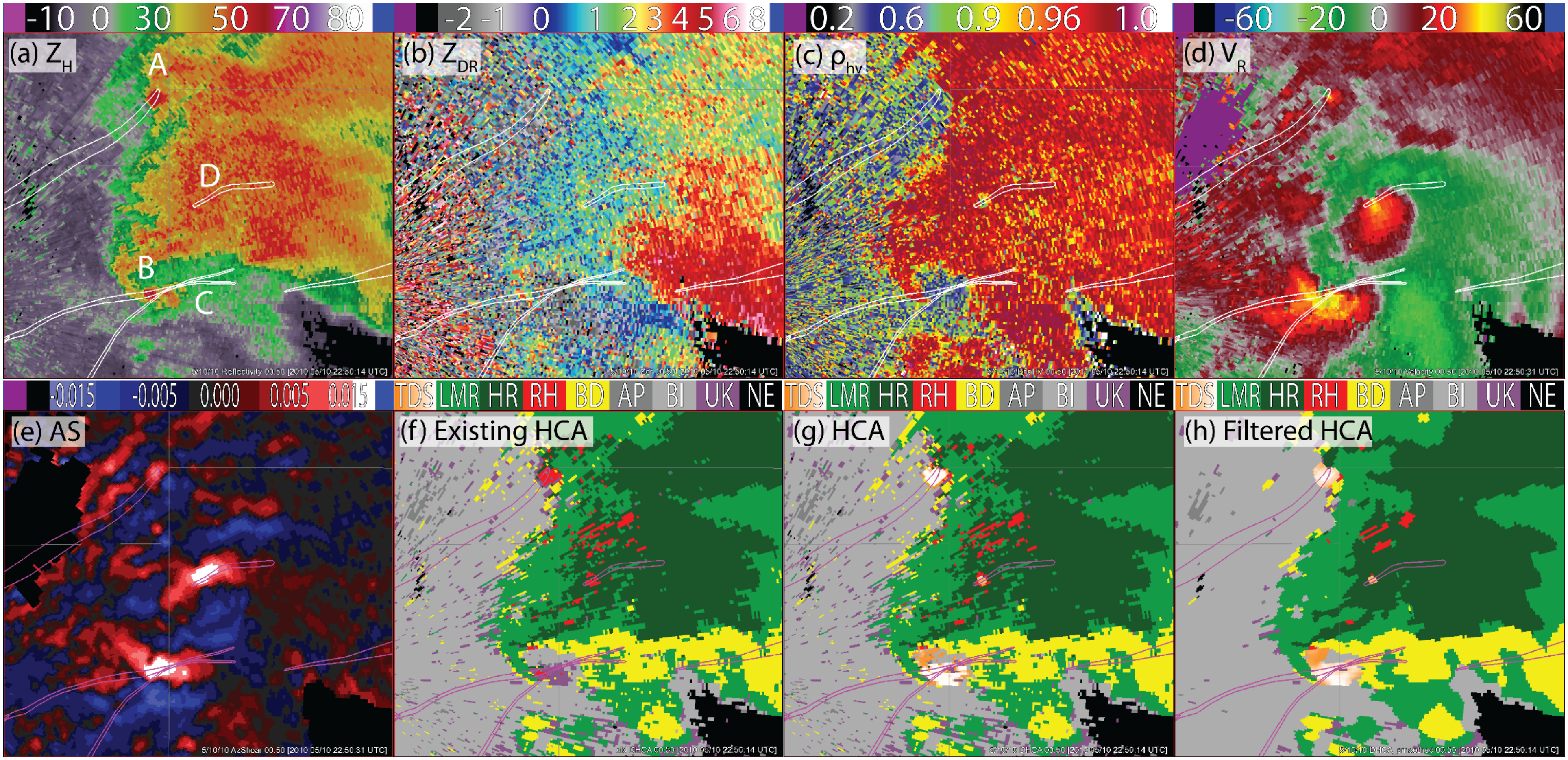
20 May 2013
KTLX

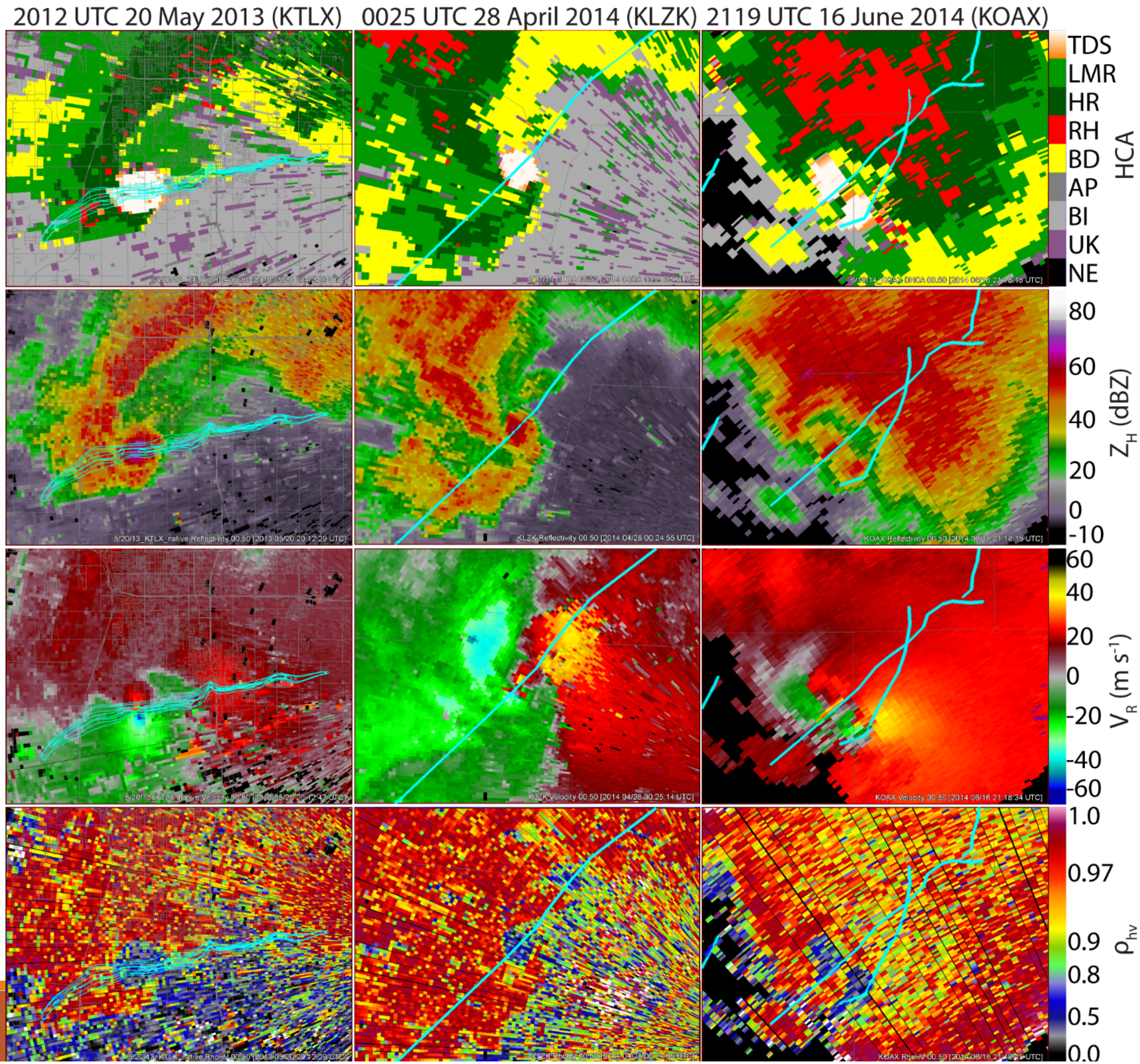


20 May 2013 - KTLX



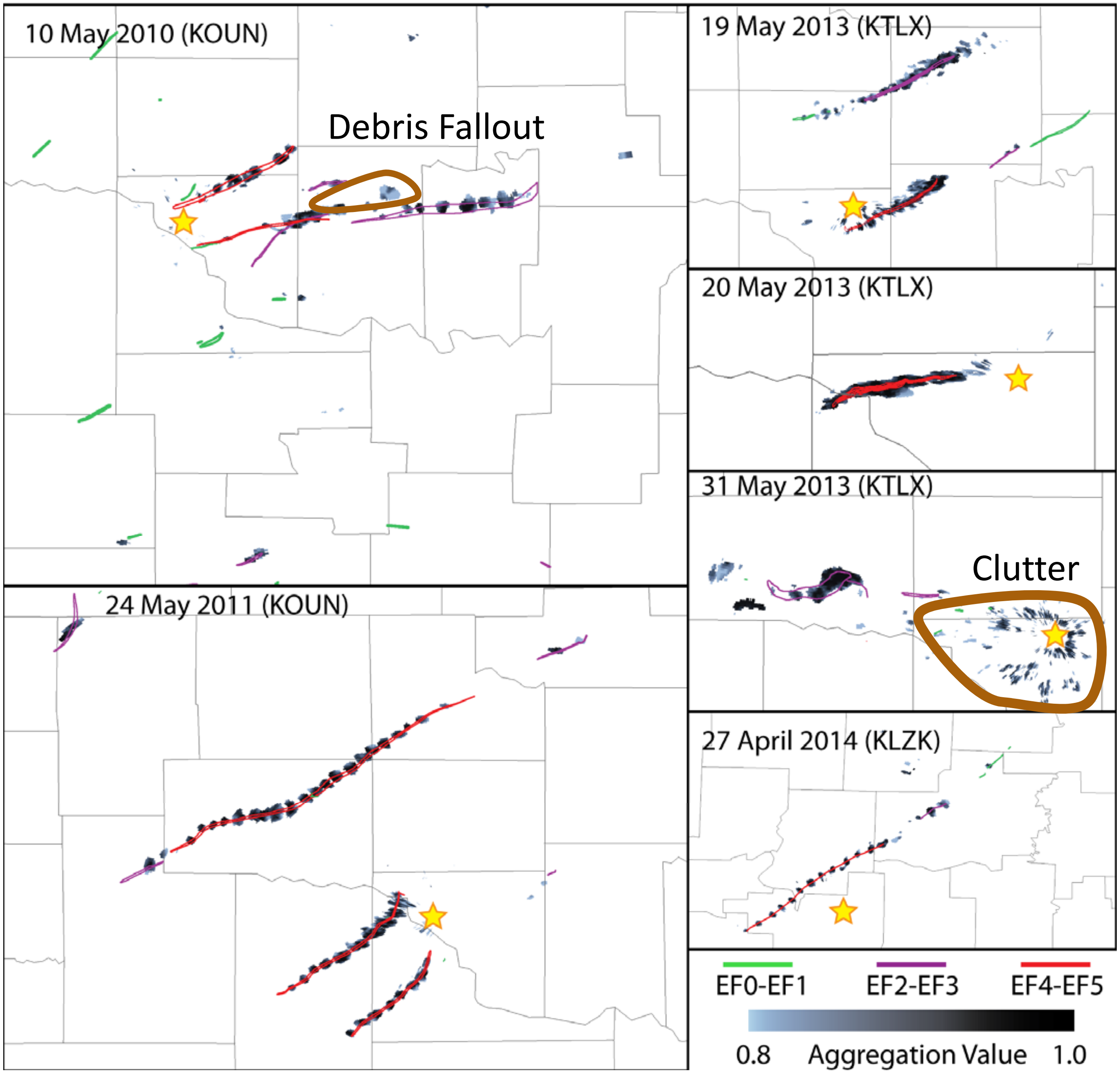
10 May 2010 (KOUN)





2012 UTC 20 May 2013 (KTLX)
0025 UTC 28 April 2014 (KLZK)
2119 UTC 16 June 2014 (KOAX)
TDS
LMR
HR
RH
BD
AP
BI
UK
NE
HCA
80
60
40
20
0
-10
Z_H (dBZ)
60
40
20
0
-20
-40
-60
V_R (m s^-1)
1.0
0.97
0.9
0.8
0.5
0.0
ρ_hv

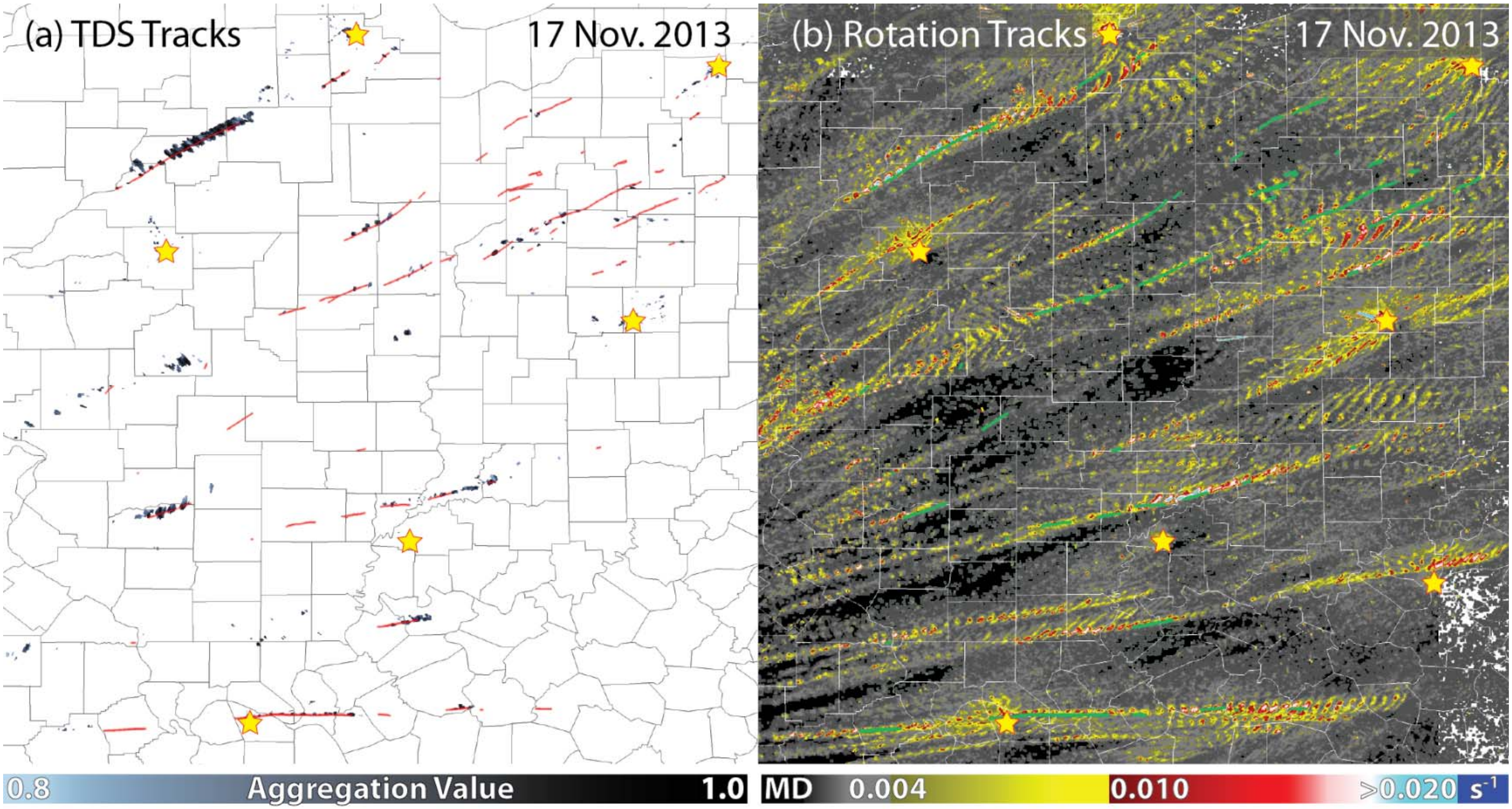
TDS Swaths



"Accumulate" areas classified as "TDS" during the course of an event (also means accumulating false positives)

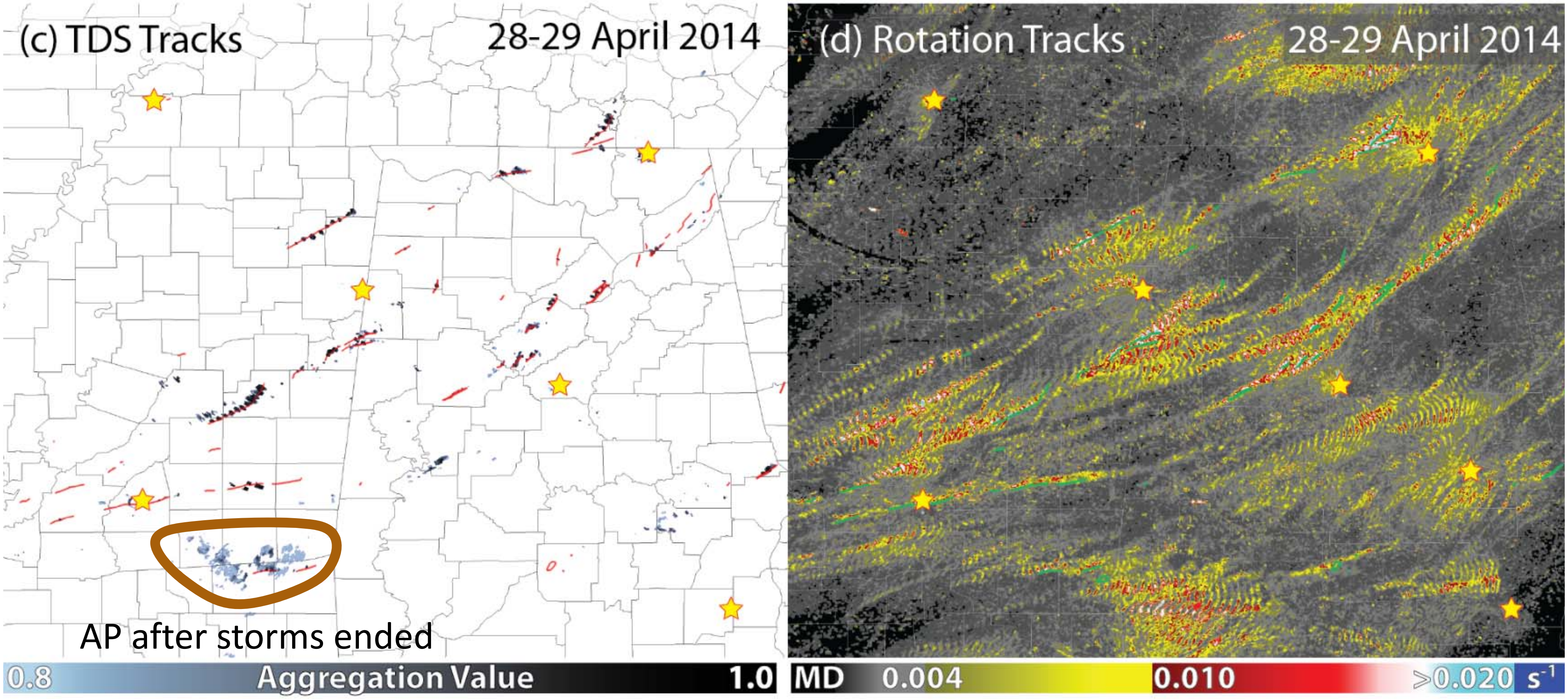
Lower agg. value areas generally false detections

Smoother tracks with SAILS scans (not shown)



— Tornado Tracks

— Tornado Tracks



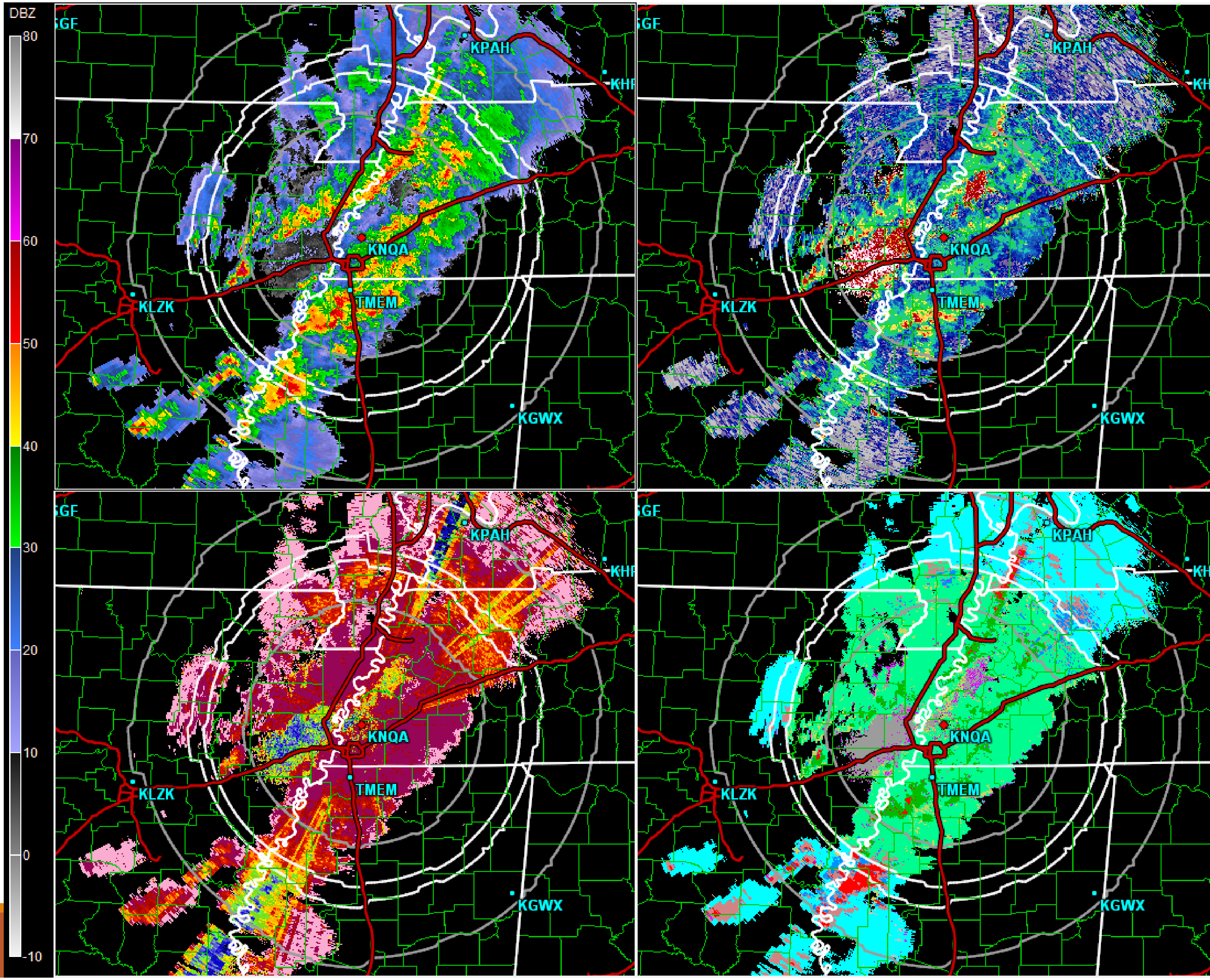
— Tornado Tracks

— Tornado Tracks

Challenges and problem areas…

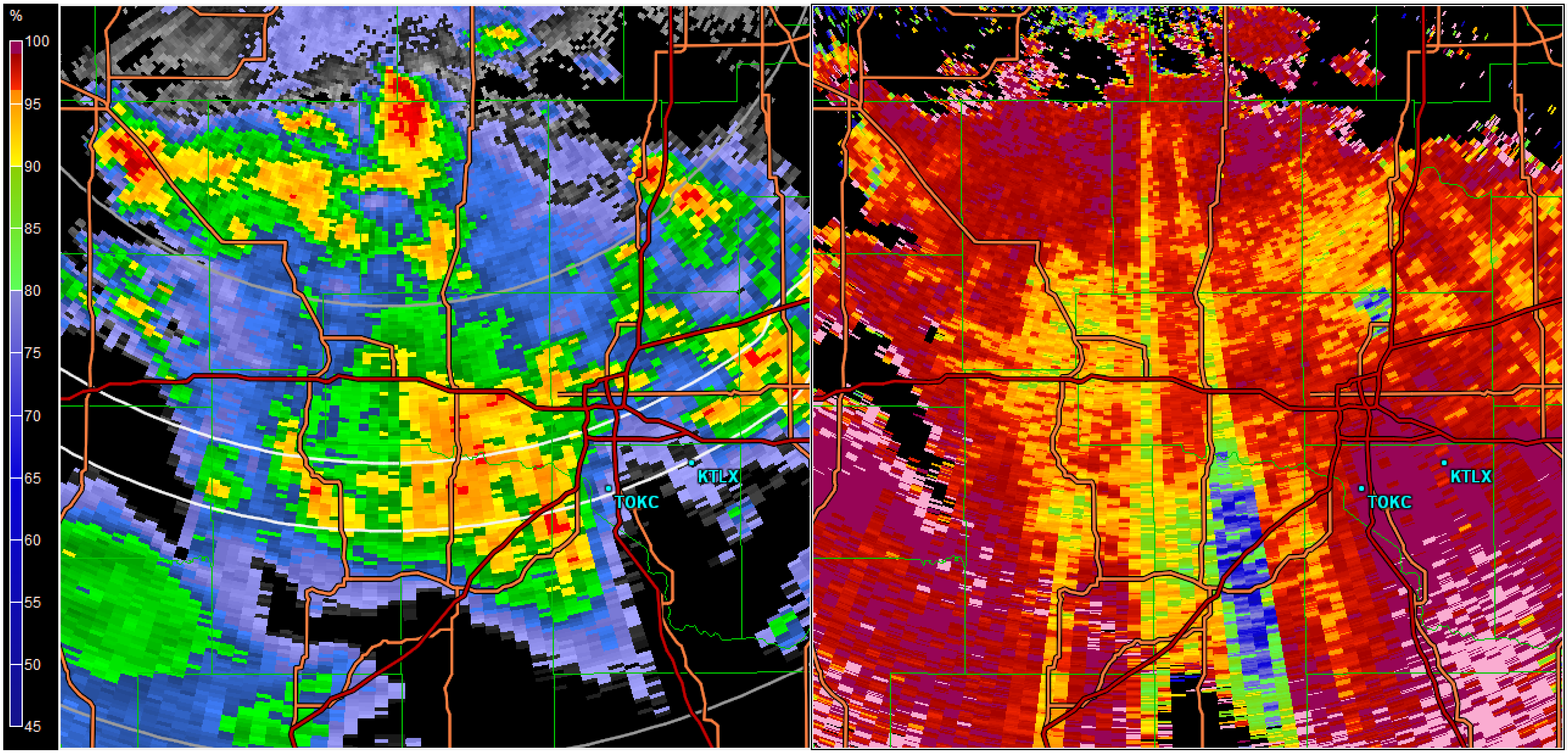
1. Non-uniform beam filling (NBF) – NBF often manifests as a radially-oriented, significant reduction in ρ_{hv}, which can be extremely detrimental to TDS classification given the discriminating power of ρ_{hv}

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*.



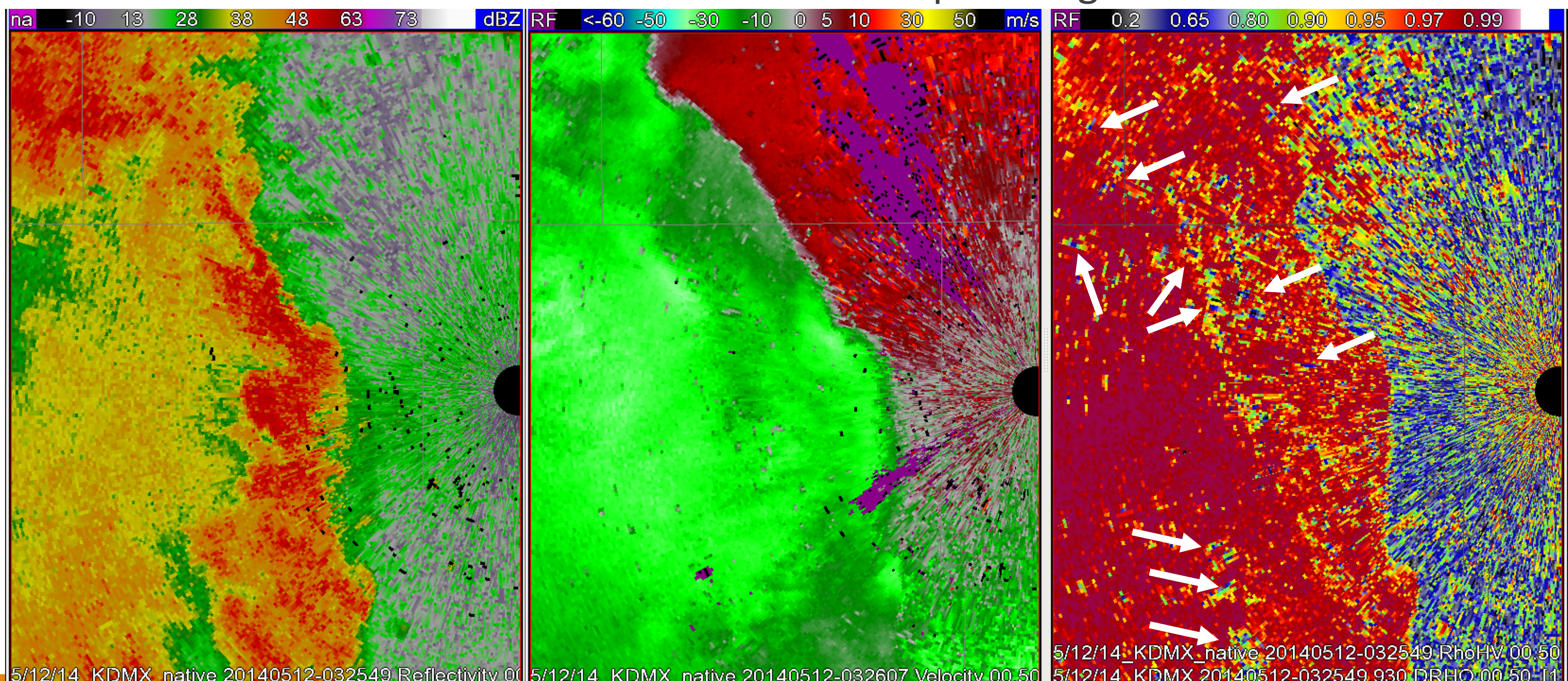
DBZ
80
70
60
50
40
30
20
10
0
-10
KPAH
KNQA
TMEM
KLZK
KGWX

NBF Effects

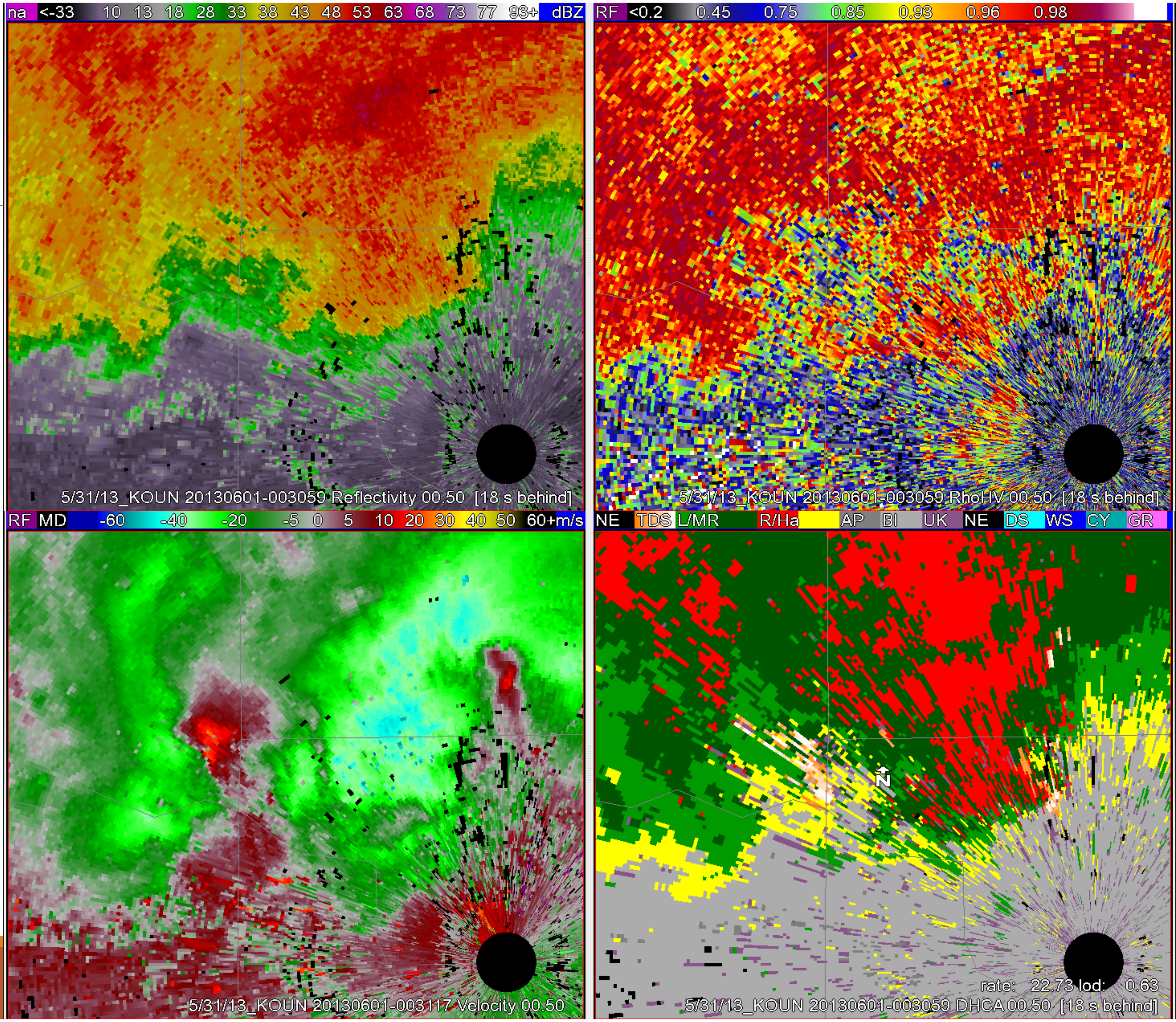


Challenges and Problem Areas…

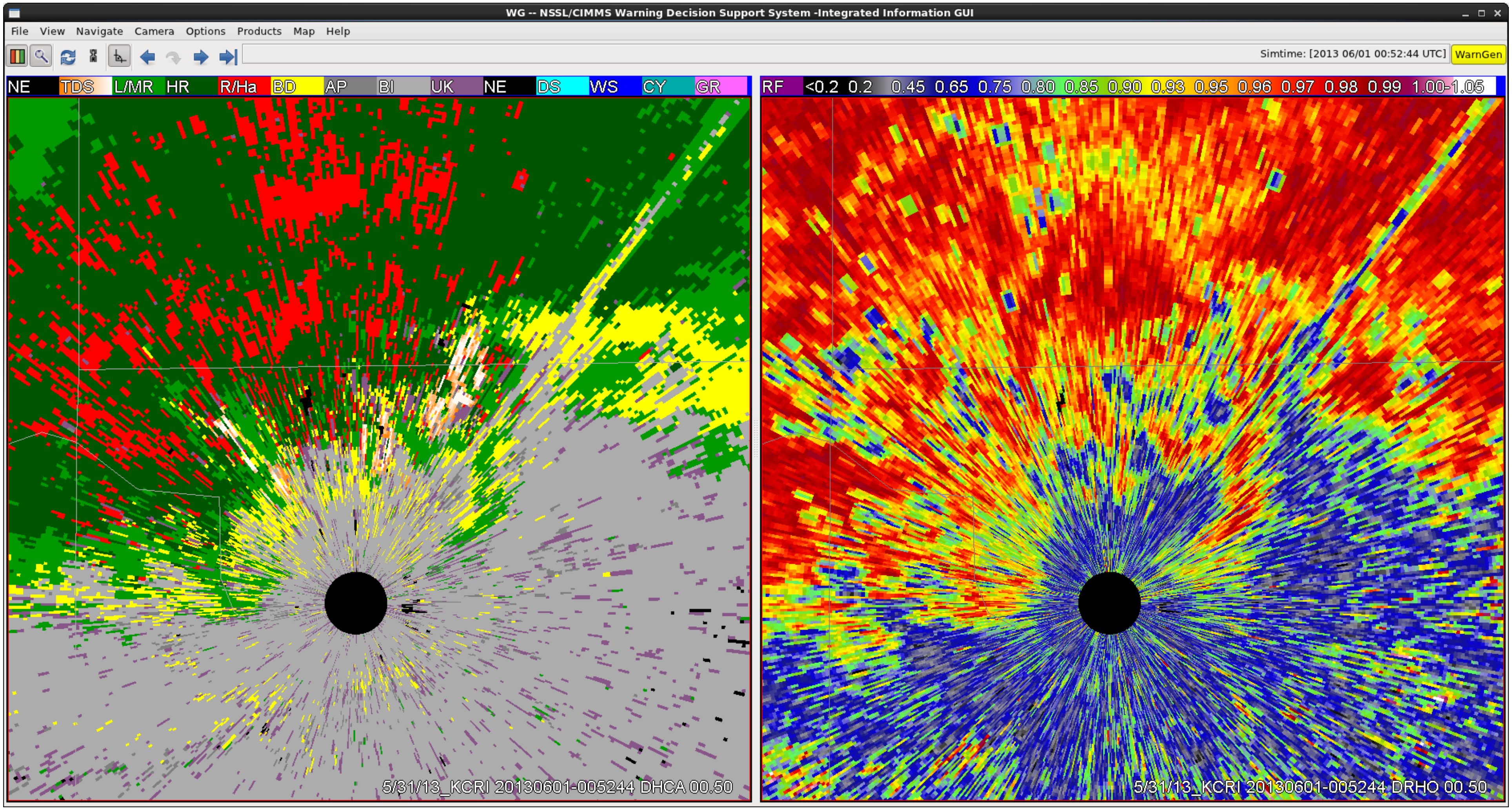
3. **Near-radar ground clutter** and data quality issues – The most common area for TDS misclassification is within ~20 km of the radar when echoes from convective storms "overlap" with ground clutter.



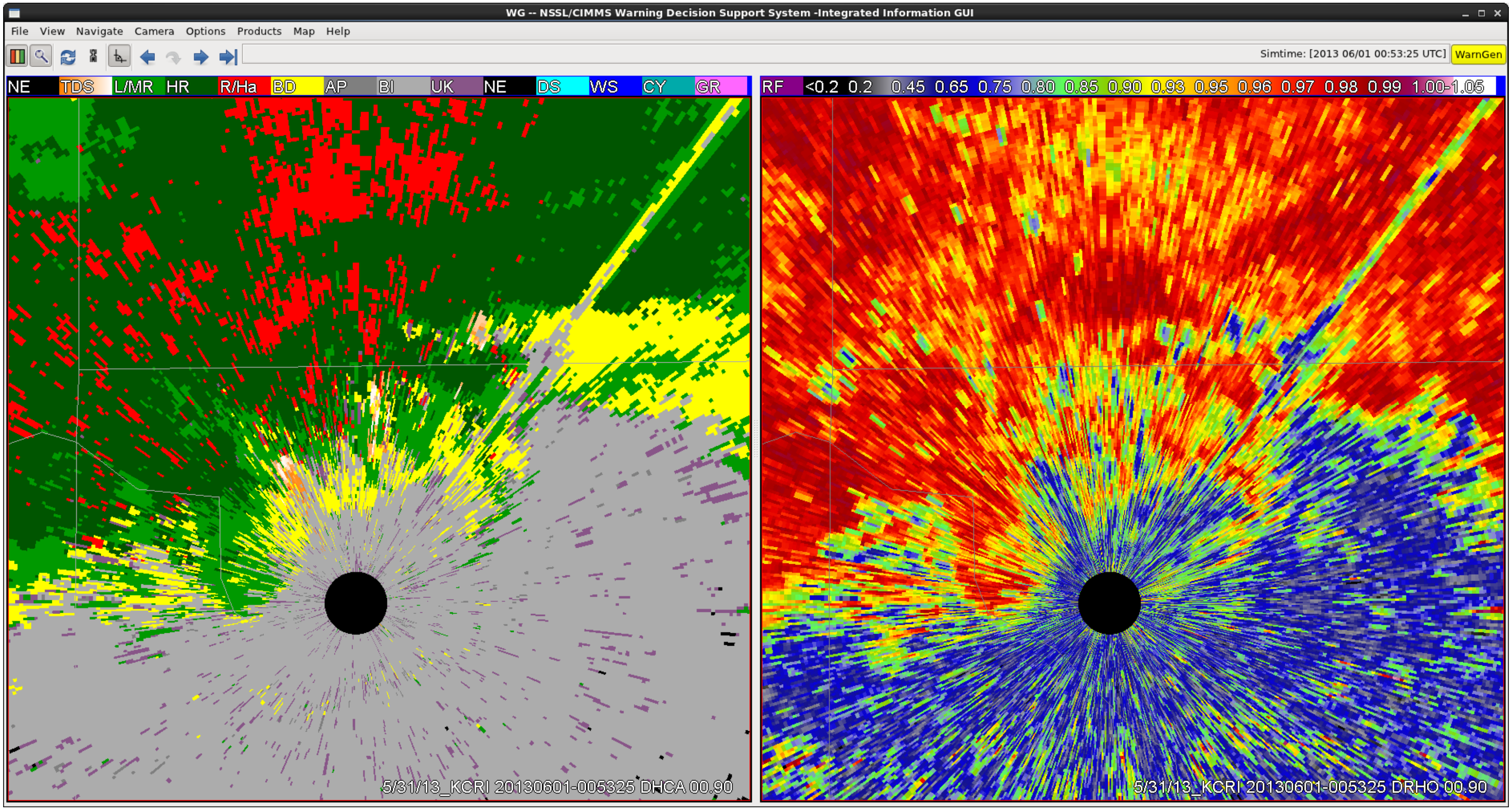
31 May 2013 - KCRI



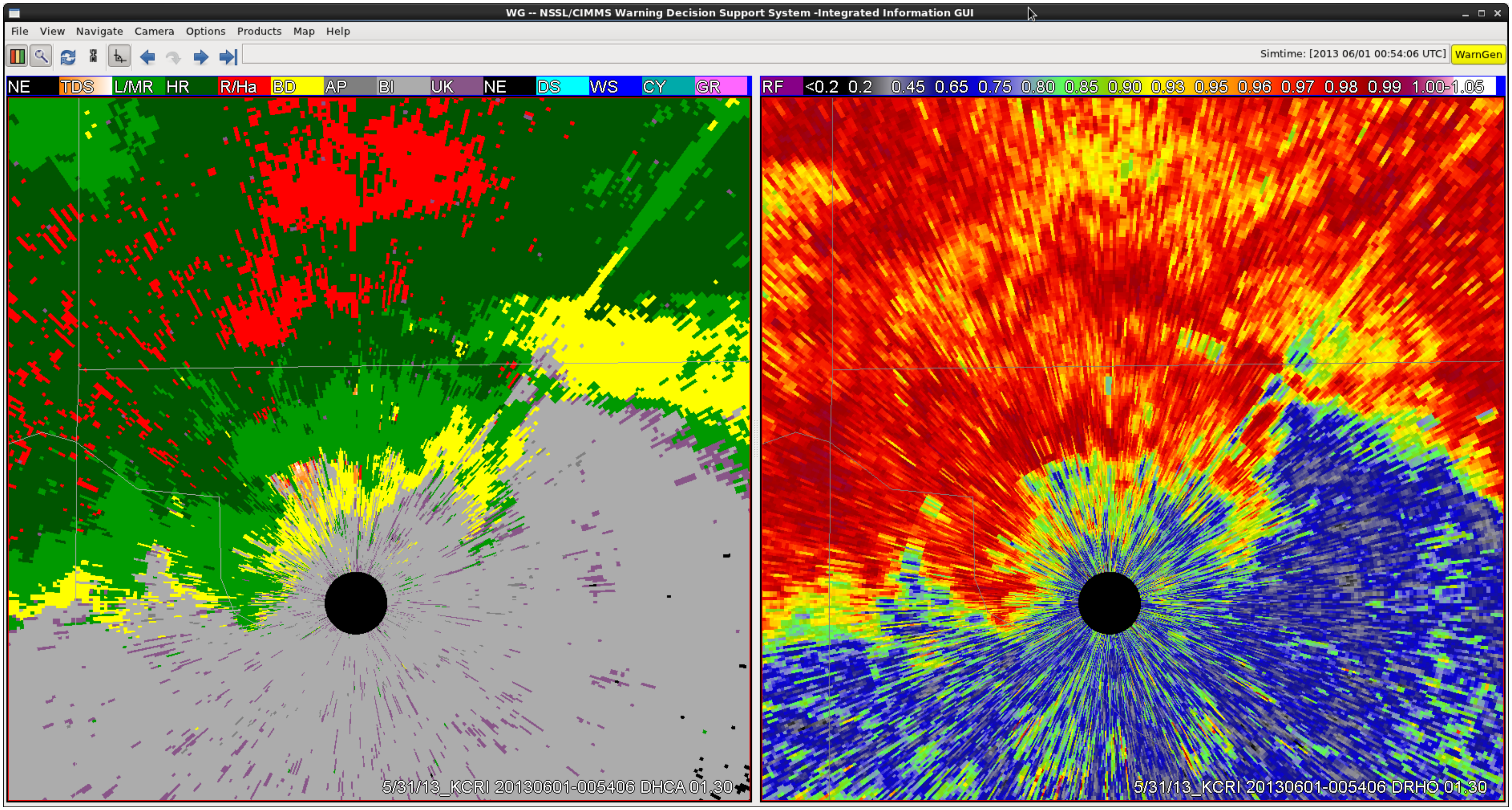
31 May 2013 KCRI – 0.5º



31 May 2013 KCRI – 0.9º



31 May 2013 KCRI – 1.3º



Challenges and Problem Areas…

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.

Validation?

How do we validate a geospatial analysis of tornado debris?

- This is probably a little easier than validating any other HCA class, but validation/verification is a challenge with any HCA given limited spatiotemporal observations

"TDS tracks" provide one way to match up TDS classifications with reported tornadoes, but this is essentially a manual process

We want to minimize false detections (with the usual FAR vs. POD trade-off), but the user will still need to use discretion

Potential Improvements

Continue to examine membership functions and weights for TDS class [e.g., based upon Kingfield et al. (2014) results]

Consider other methods to mitigate "false positives". Examples:

- Smooth (e.g., mode filter) HCA output more aggressively or require a minimum neighborhood size (e.g., only allow TDS at gate "X" if there are 9 other TDS gates within a 5 gate x 3 radial neighborhood centered on gate "X") – Only use TDS in the "Hybrid HCA" product used for QPE?
- Require that any gate for which the TDS class is selected be within 10 km of ZH > 50 dBZ on a ~3 km AGL CAPPI. This will reduce AP-related misclassification and essentially only allow TDSs near convective storms
- Develop a method to reduce misclassification from near-radar ground clutter contamination (e.g., $\frac{\partial \rho_{hv}}{\partial t}$ threshold?) (or await CLEAN-AP?)
- Use environmental data to limit TDS classification to environments that support convective storms (e.g., require MUCAPE > 100 j/kg) – requires full grid of environmental data (not single-location / point sounding data)