OBJECTIVE IDENTIFICATION AND TRACKING OF Z_{DR} COLUMNS IN X-BAND RADAR OBSERVATIONS

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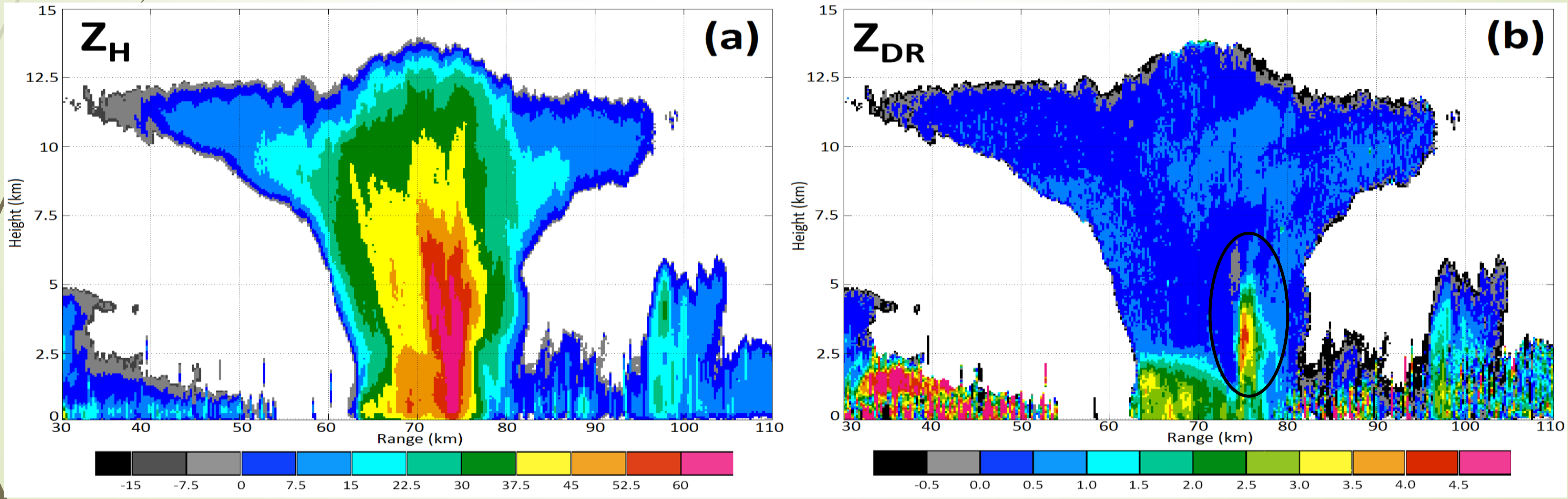
Z_{DR} Columns

- Definition: Enhanced Z_{DR} (1-5 dB) extending about 1-4km above the 0° C level.
- Polarimetric signature associated with updraft in convective storms.
- Contain supercooled liquid raindrops.



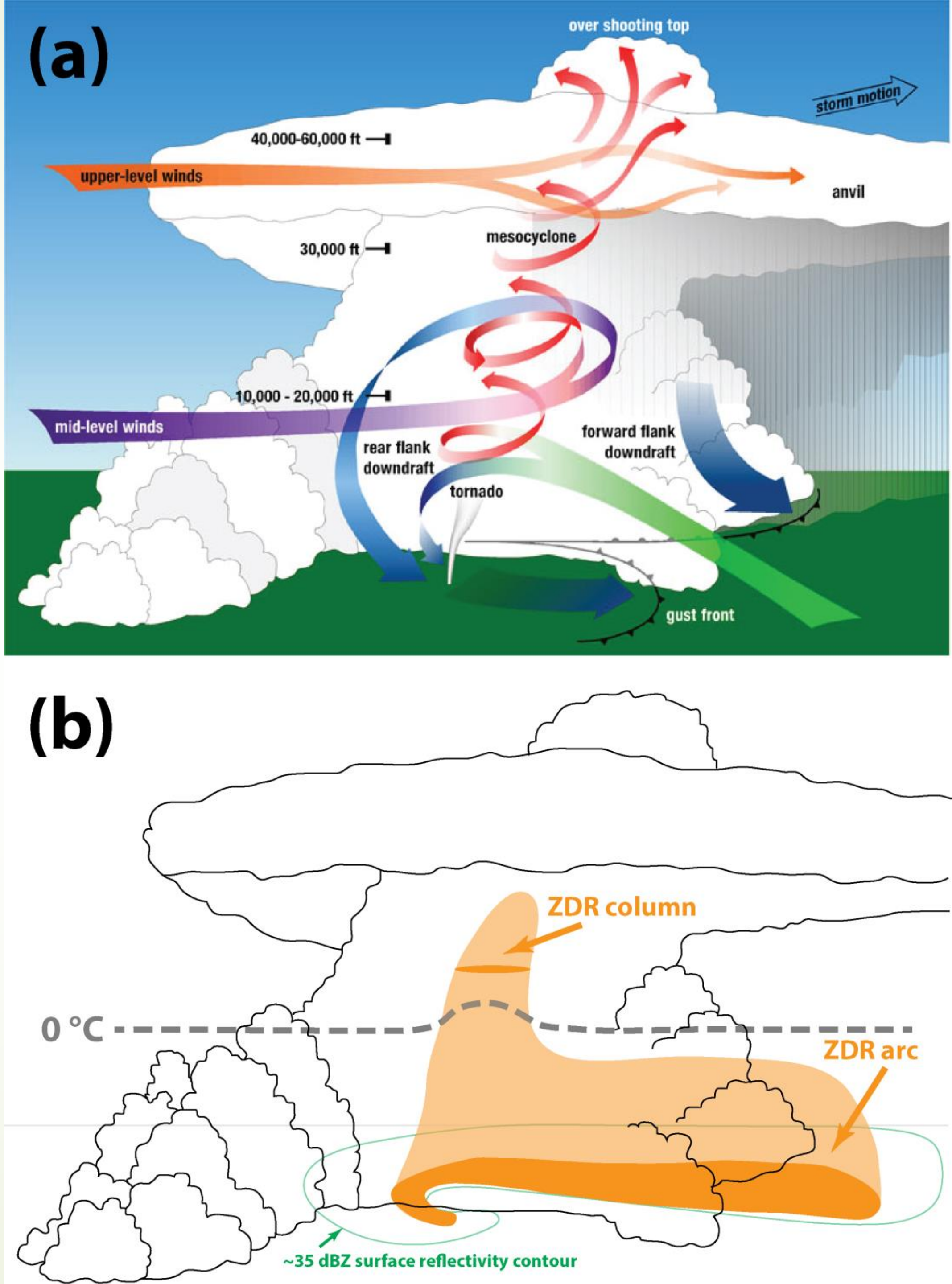
Kumjian et al. (2014)

Z_{DR} Columns – so what?

- Z_{DR} columns have practical applications:
  - Location of updraft.
  - Z_{DR} column properties related to updraft strength.
  - Could be a predictor for heavy rainfall and/or hail – Picca et al. (2010).
  - Relationship to low-level rotation through vorticity stretching?

Long Term Goal

- Can Z_{DR} columns be used as a prognostic tool for low-level rotation?
- We want to determine if measurable Z_{DR} column properties (which are connected to updraft strength) can be a predictive tool for tornadogenesis.
- Objective identification and tracking of Z_{DR} columns is just the first step to our long-term goal.

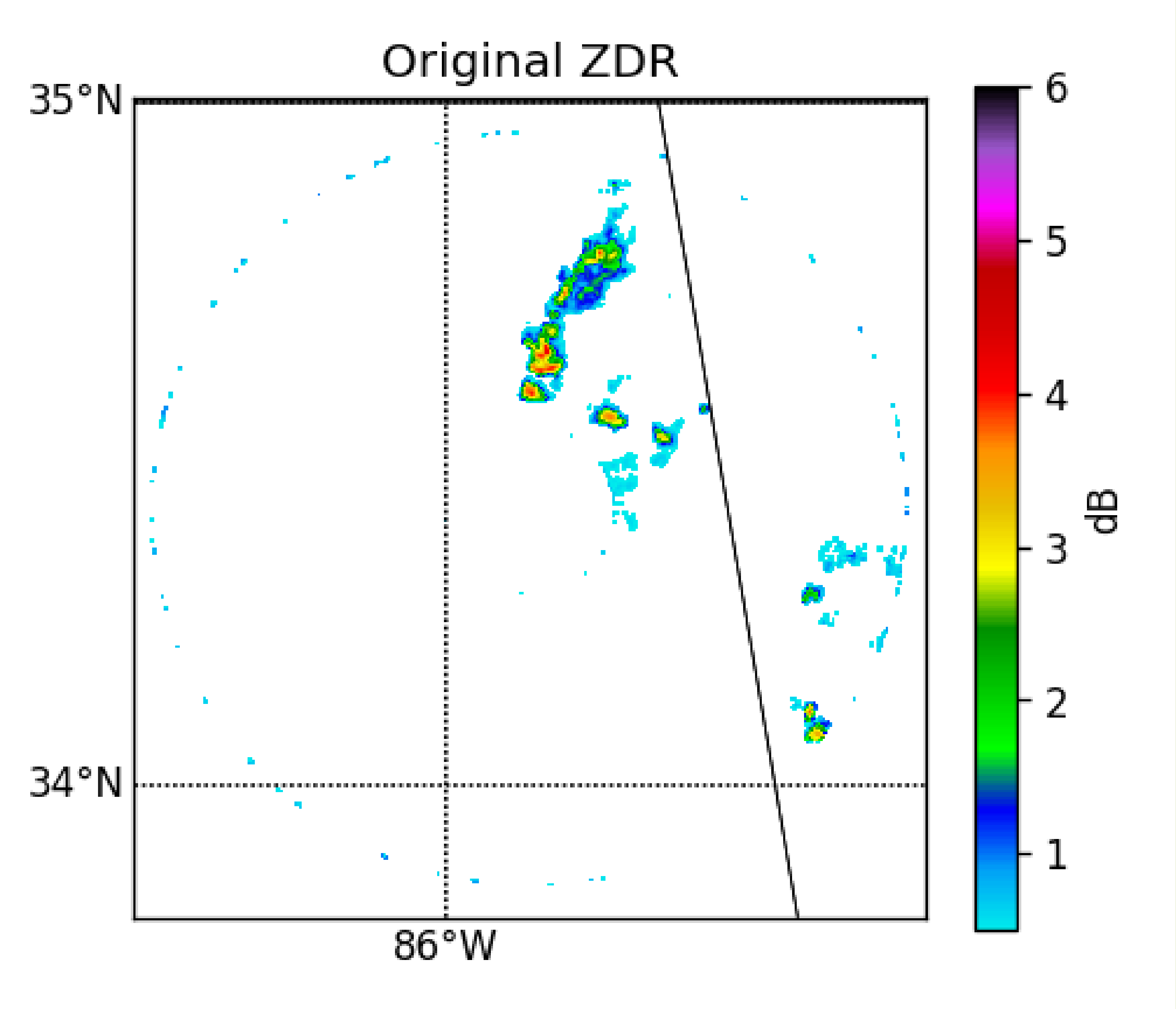


Objective Identification and Tracking Algorithms

- Enhanced Watershed Algorithm (EWA; Lakshmanan et al. 2009).
- Tracking algorithm in Lakshmanan and Smith (2010).

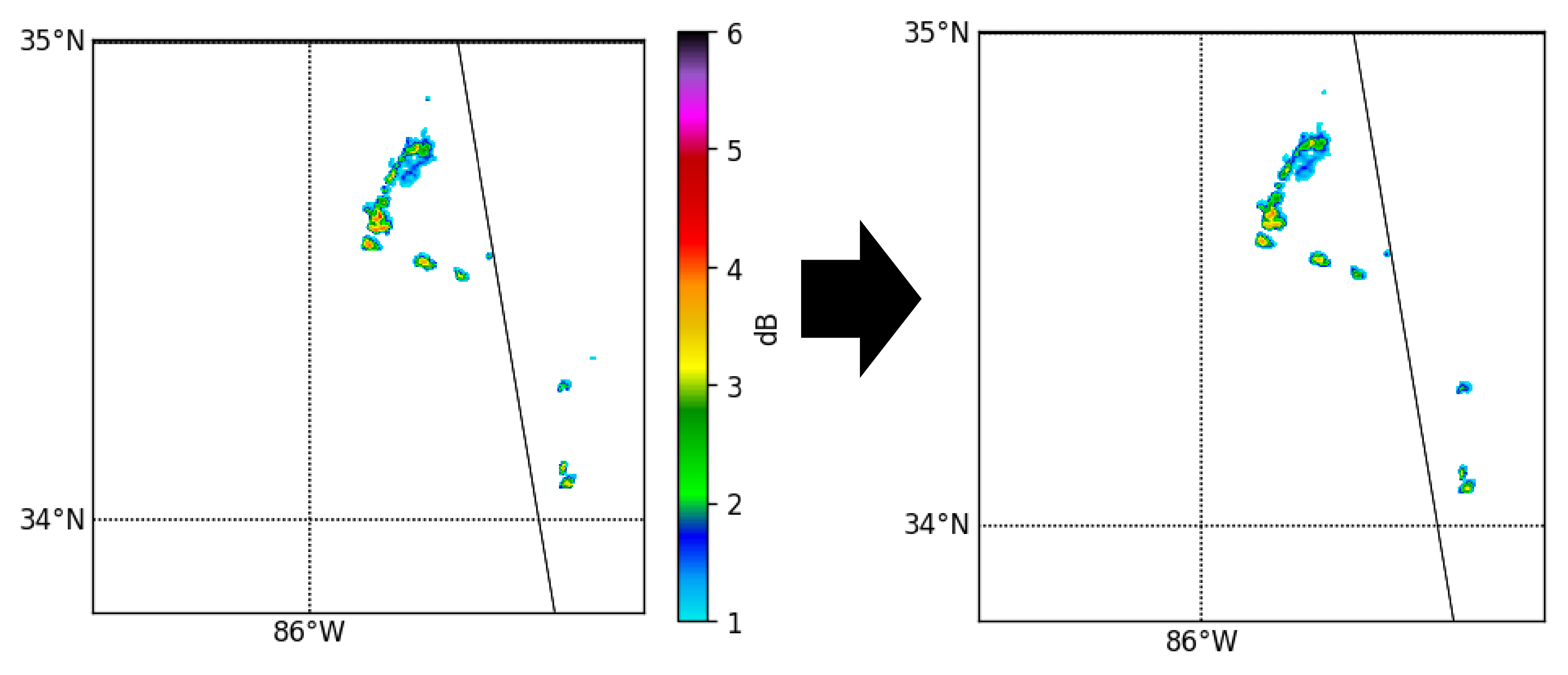
Implementation of EWA

- Map radar data to a 2-D surface with Py-ART (Helmus and Collis 2016).
  - Cressman weighting function and a constant radius of influence (750 m).



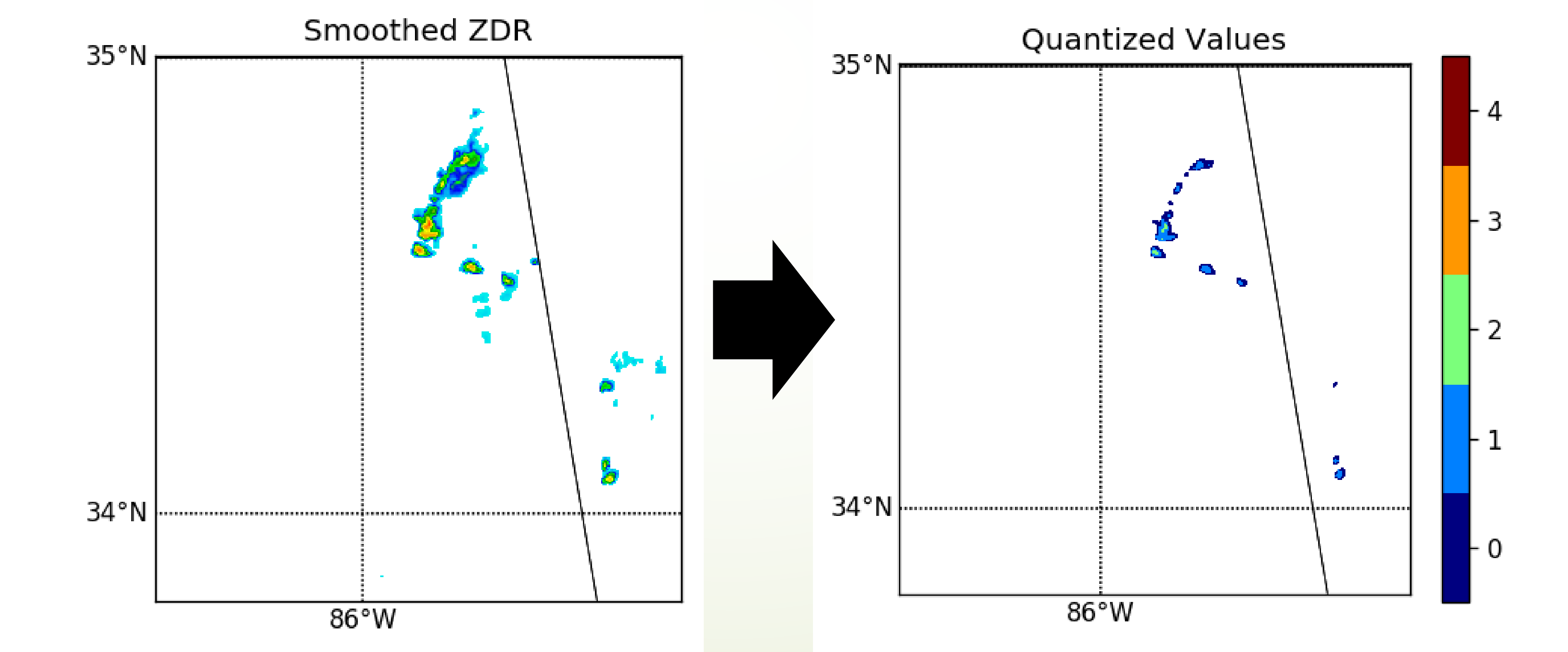
Implementation of EWA

- Smooth the data.
  - This is done using a Gaussian filter.



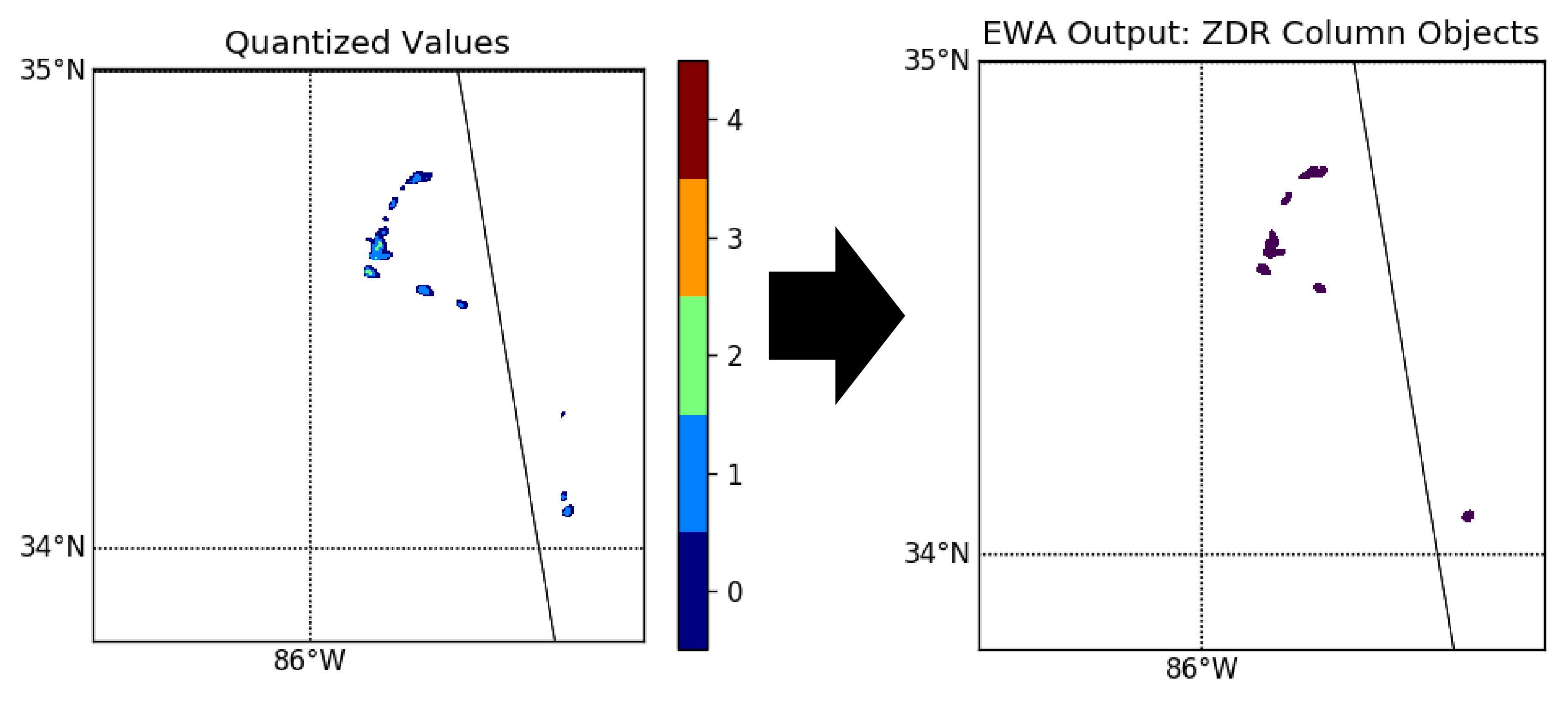
Implementation of EWA

- Quantize the data.
  - Place upper and lower bound on data and then round values in between these bounds to nearest integer.



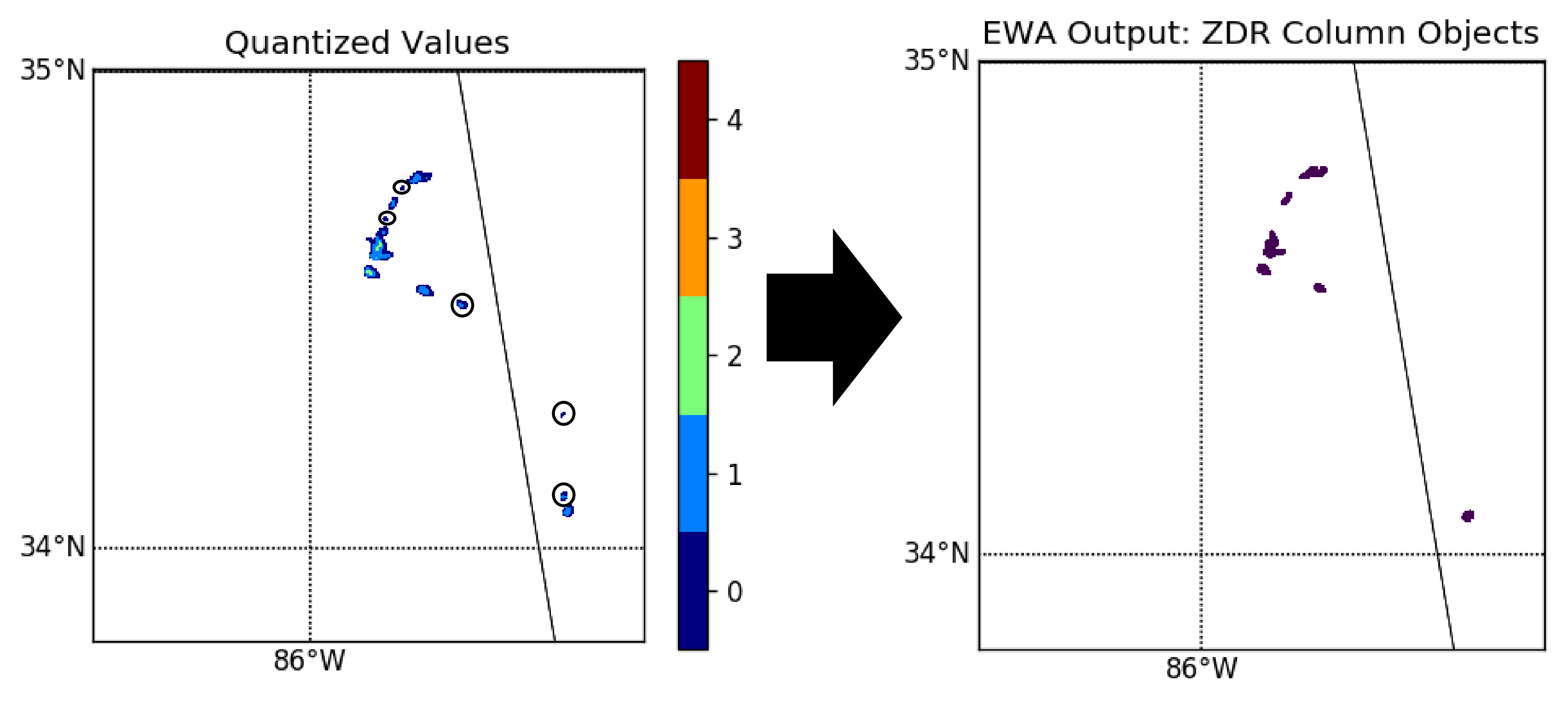
Implementation of EWA

- Capture Z_{DR} columns.
  - Immerse the field starting at centers and assigning pixels to a Z_{DR} column objects and decreasing in intensity values until it reaches the hysteresis level.



Implementation of EWA

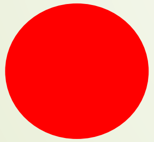
- Sizing check
  - A threshold is put on the areal extent of the Z_{DR} column objects.



Tracking Algorithm

- The tracking algorithm in Lakshmanan and Smith (2010) is used.
- Uses Z_{DR} column objects identified by EWA.

Example Z_{DR} column object

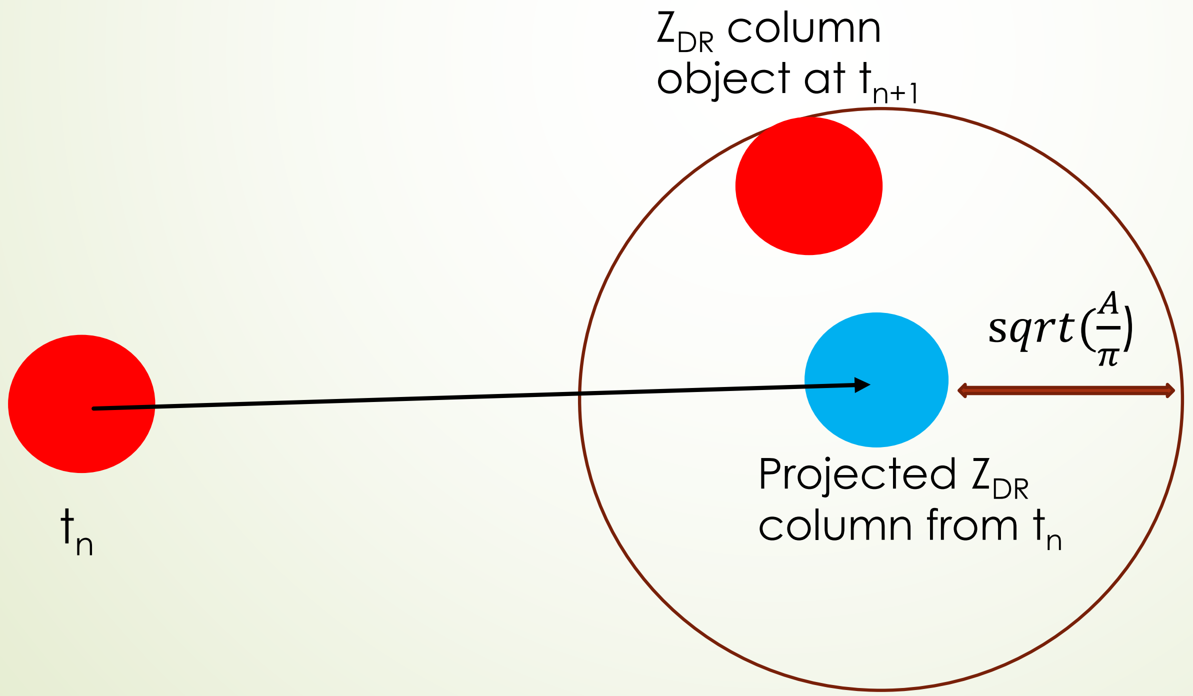


Tracking Algorithm

- Z_{DR} column objects identified at t_n are projected to their expected position at t_{n+1}
- Projected forward by the average vector for established track or by the Bunkers storm motion for new Z_{DR} columns with no track.

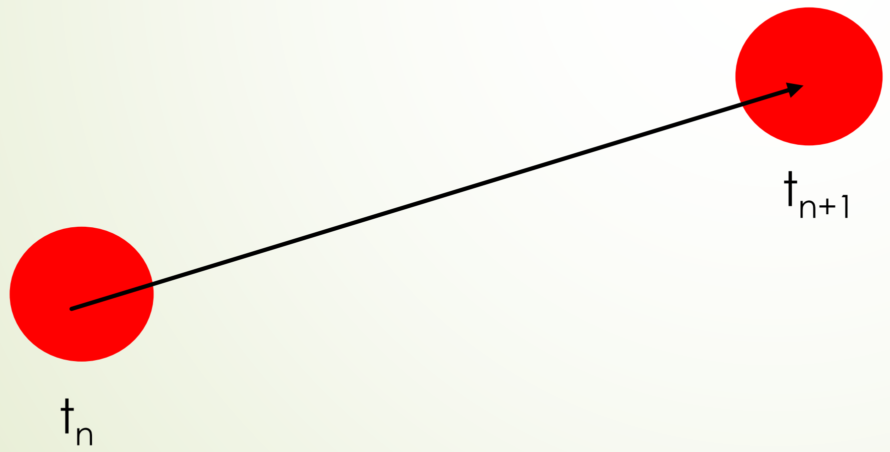
Tracking Algorithm

- Identify Z_{DR} column objects at t_{n+1} within search radius of projected cell.



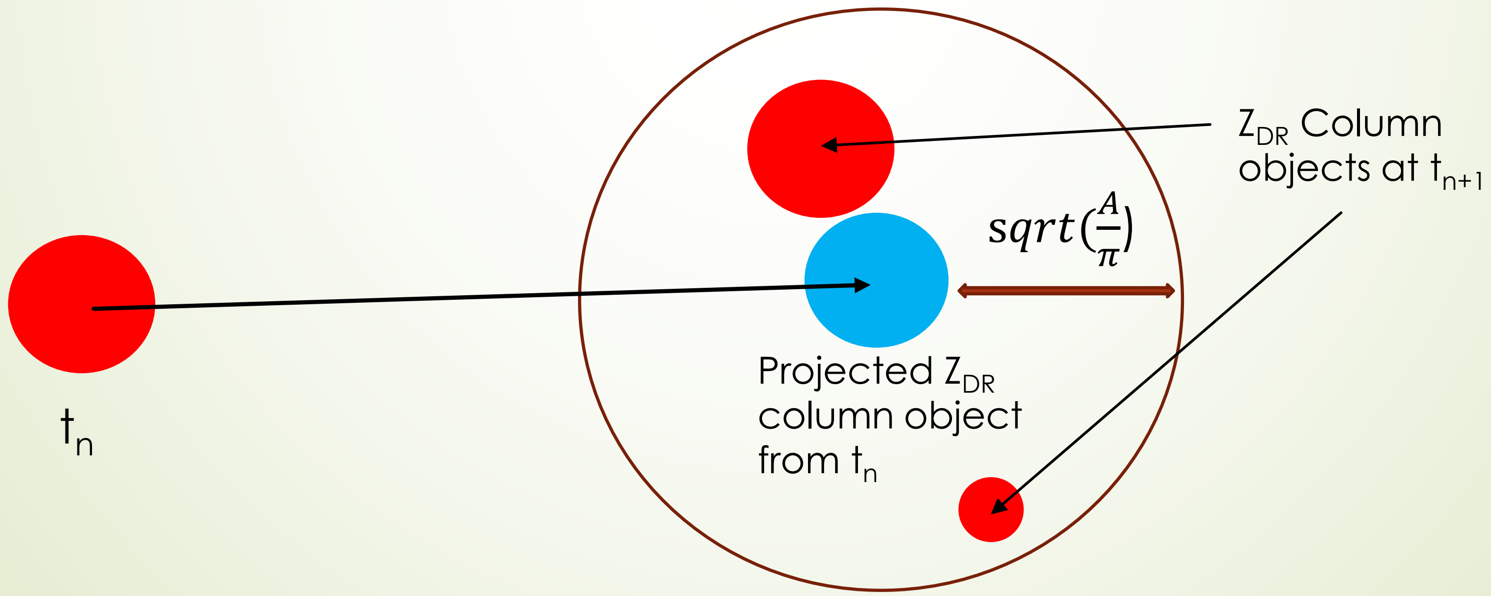
Tracking Algorithm

- If there is only one Z_{DR} column within the search radius, the two Z_{DR} columns are matched and a track is drawn.



Tracking Algorithm

- If there is more than one Z_{DR} column inside of the search radius, a cost function incorporating distance, area and peak value are used to determine which one to match with.



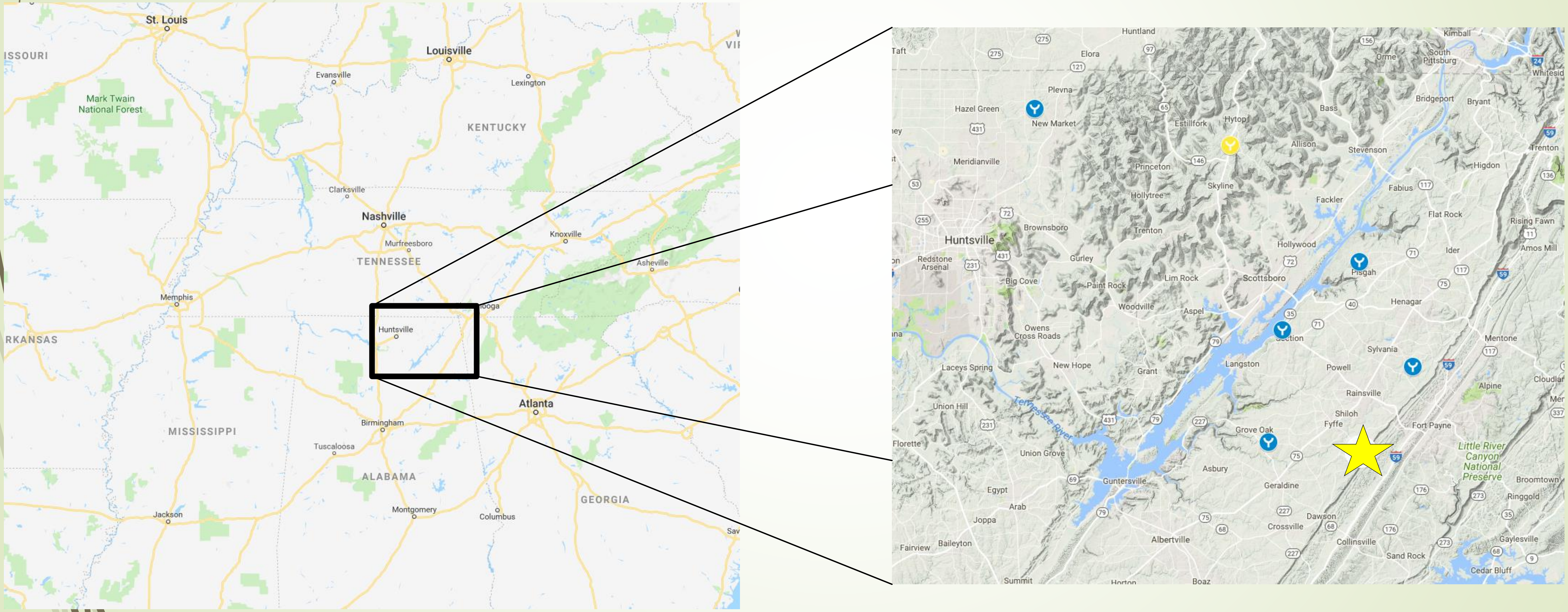
UMass X-Pol

	UMass X-Pol
Pulse Repetition Frequencies	2.4/1.6/0.51 kHz (triple PRT)
Transmitted Power	5 kW (per polarization)
Half-power beam width	1.2°
Range resolution	60 m
Max/min unambiguous velocity	+/- 38.2 ms^{-1} (dual PRT)
Wavelength	3 cm (X-band)
Max unambiguous range	60 km
Max azimuthal scan rate	24° s^{-1}

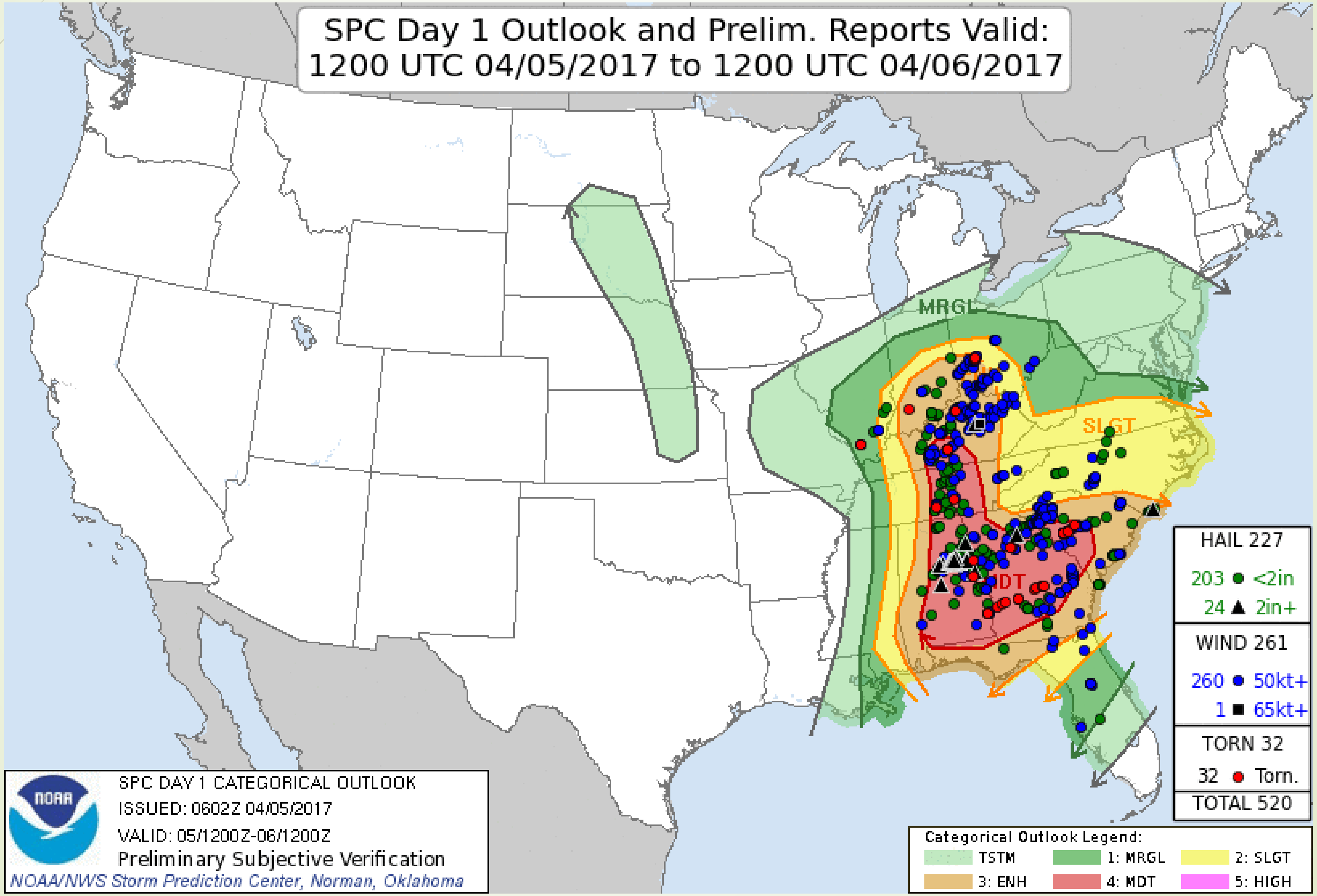
VORTEX-SE

- Overall Mission: Understand tornadoes and their environments in the southeast United States.
- Domain: Northern Alabama
  - Mobile radars couldn’t do traditional storm chasing.
  - Radar remained stationary due to terrain, trees, bad road network.
- Participated in eight Intensive Observing Periods (IOPs) over two seasons

Case: 5 April 2017, IOP3b

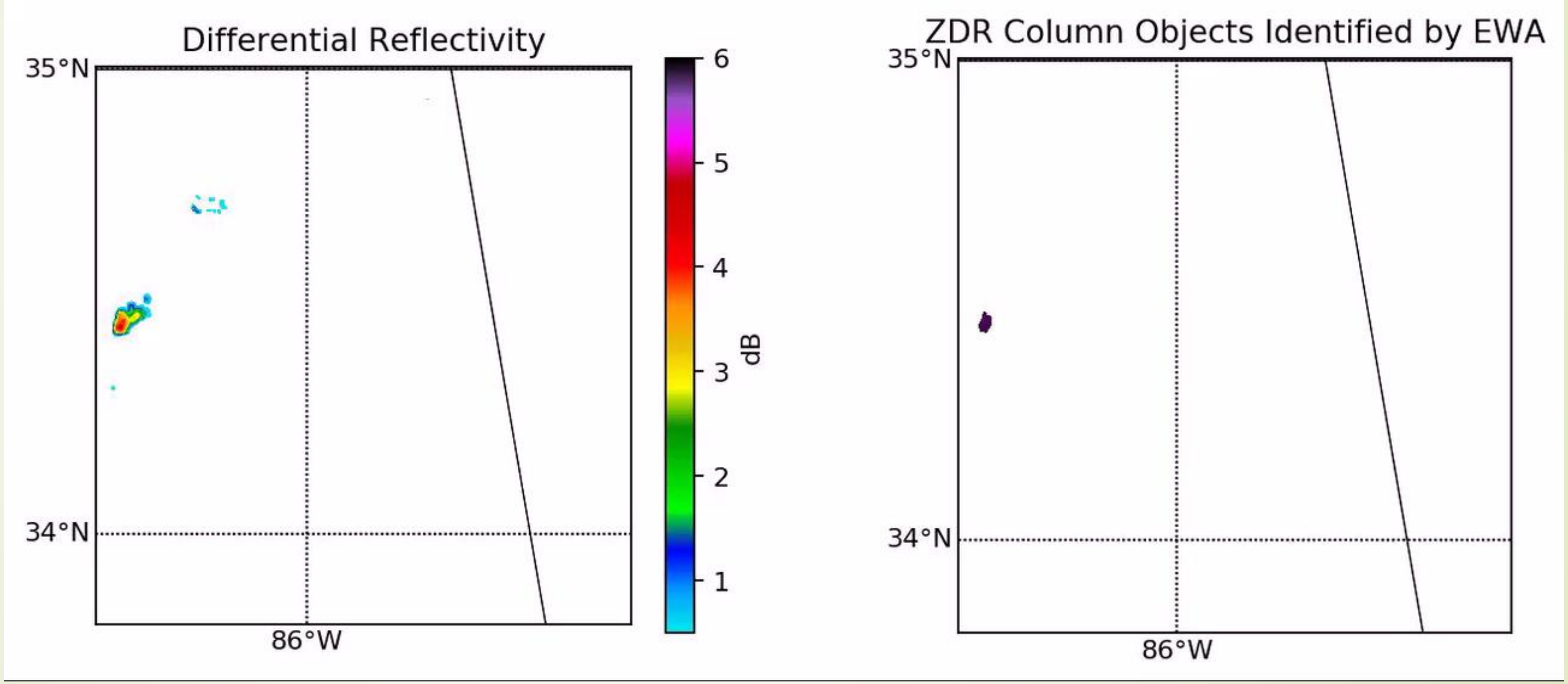


Case: 5 April 2017, IOP3b

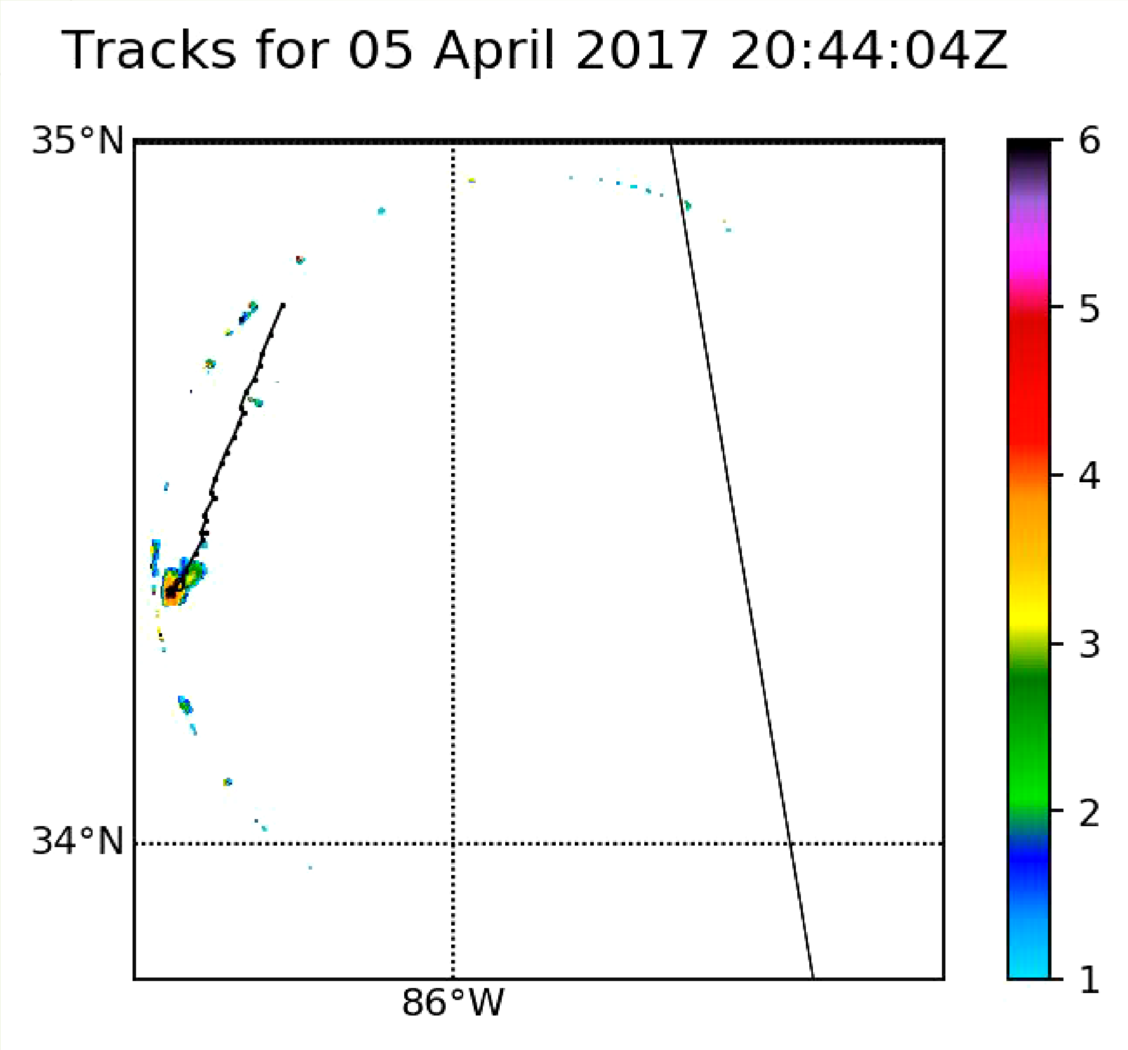


Case: 5 April 2017, IOP3b

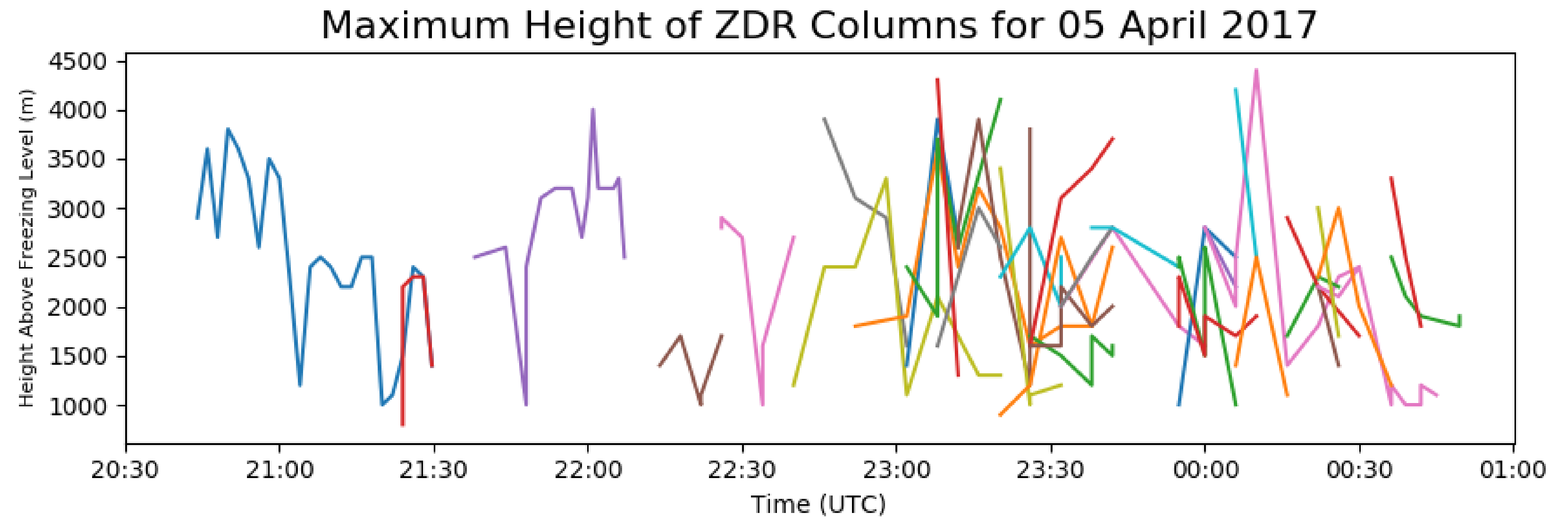
Animated EWA Columns

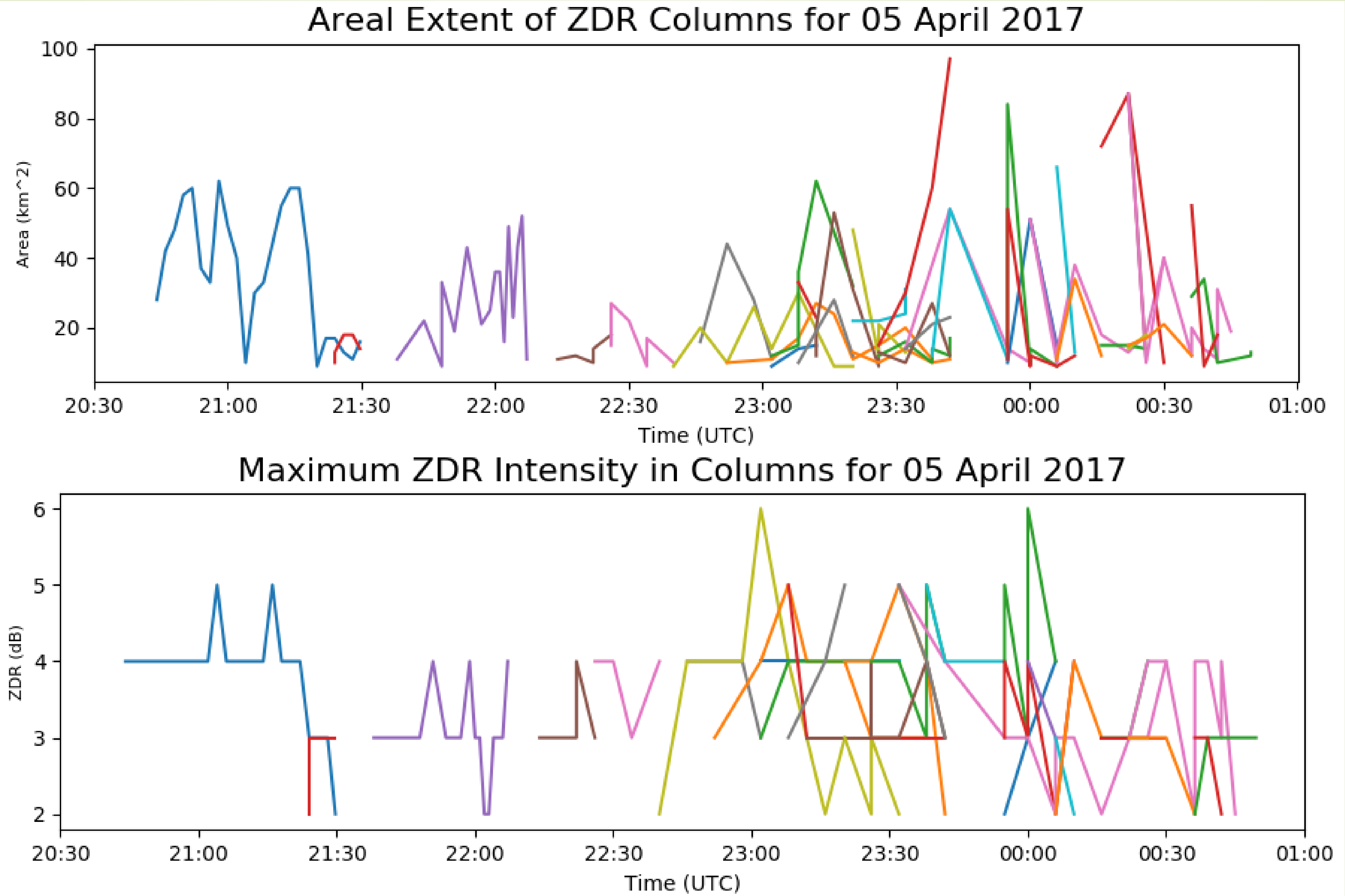


Animation of Tracks



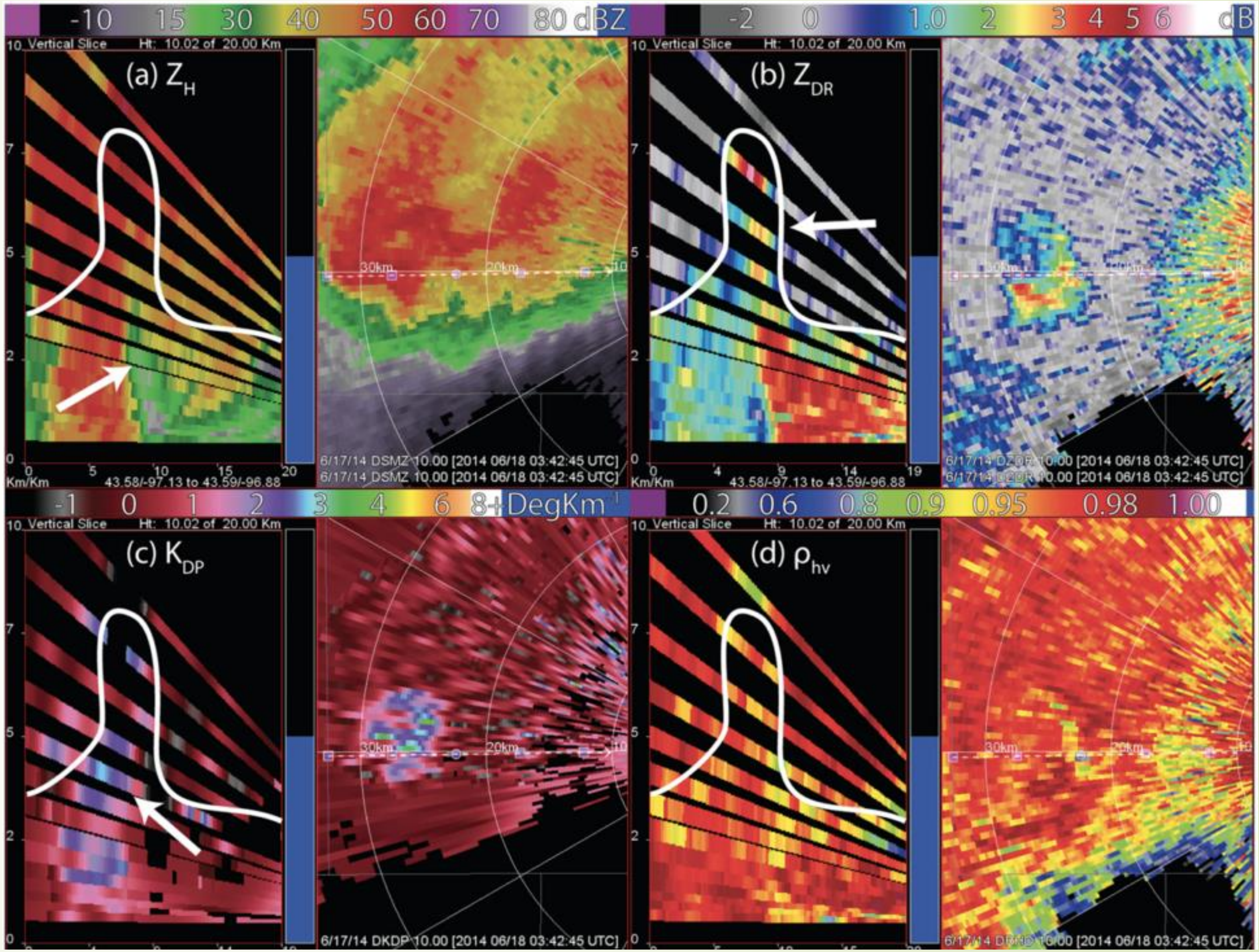
Time Series Plots




Areal Extent of ZDR Columns for 05 April 2017
Area (km^2)
100
80
60
40
20
20:30
21:00
21:30
22:00
22:30
23:00
23:30
00:00
00:30
01:00
Time (UTC)
Maximum ZDR Intensity in Columns for 05 April 2017
ZDR (dB)
6
5
4
3
2
20:30
21:00
21:30
22:00
22:30
23:00
23:30
00:00
00:30
01:00
Time (UTC)

Conclusions

- Z_{DR} columns can be objectively identified with the EWA.
- Z_{DR} columns can be tracked in time while also retaining valuable information about them such as height above freezing level, areal extent, and peak Z_{DR} value.
- It is important to obtain higher resolution data of Z_{DR} columns to properly study them.



Snyder et al. (2015)

Future Directions

- Apply these algorithms to WSR-88D data and see how they perform in comparison to higher resolution data.
- End Goal: We want to determine if measurable Z_{DR} column properties (which are connected to updraft strength) can be a predictive tool to tornadogenesis.

THANK YOU!

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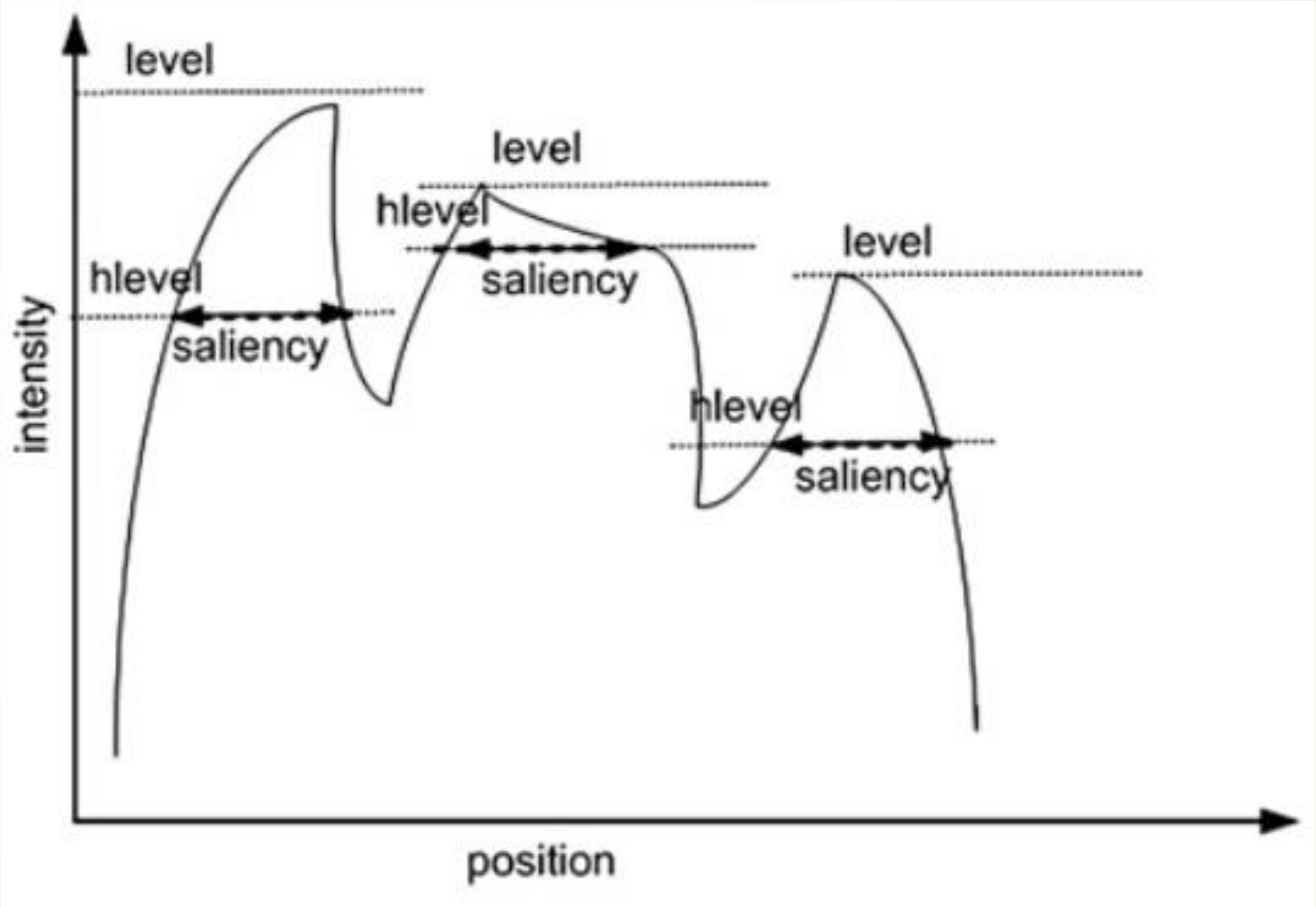
BONUS SLIDES

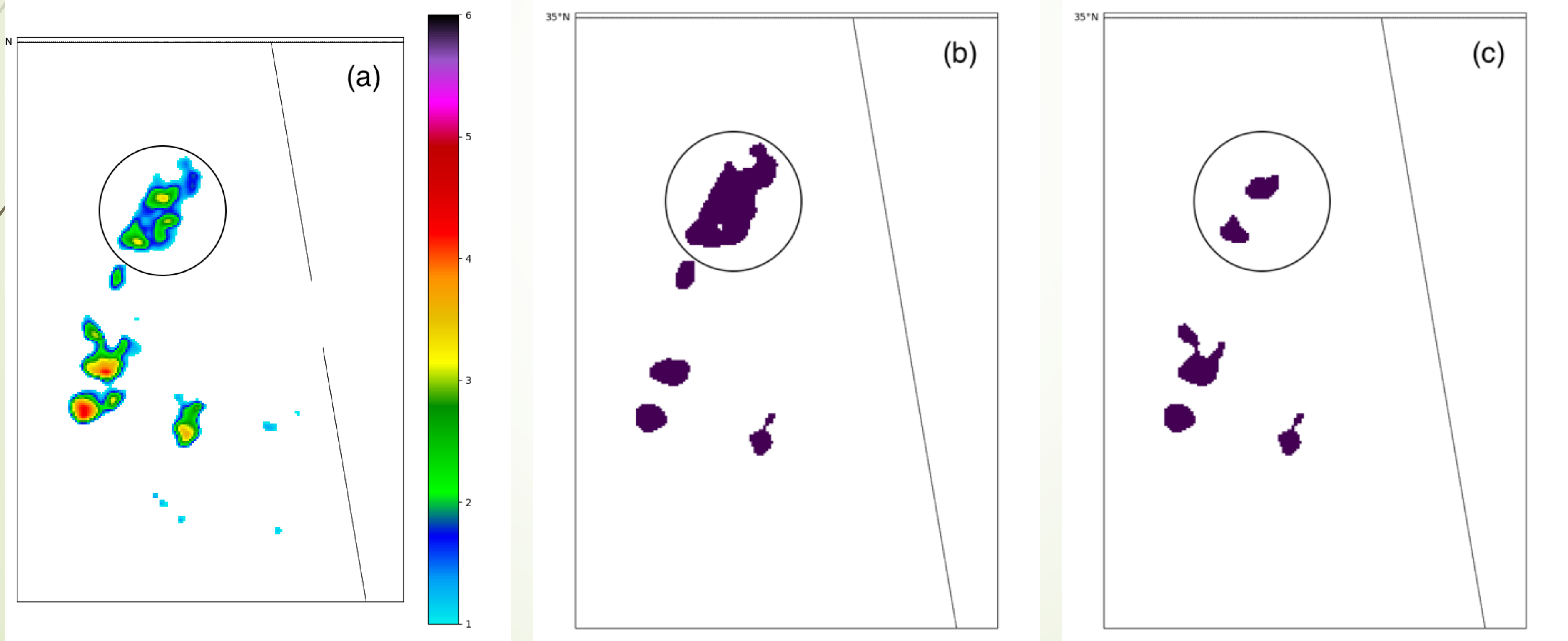
Determining Parameters for EWA and Tracking Algorithm

- Two main parameters that needed to be determined:
  - Hysteresis level
  - Saliency level
- Other parameters that could be altered:
  - Smoothing technique
  - Search radius



Hysteresis level

- Adjusting the hysteresis level can affect how the EWA identifies columns.

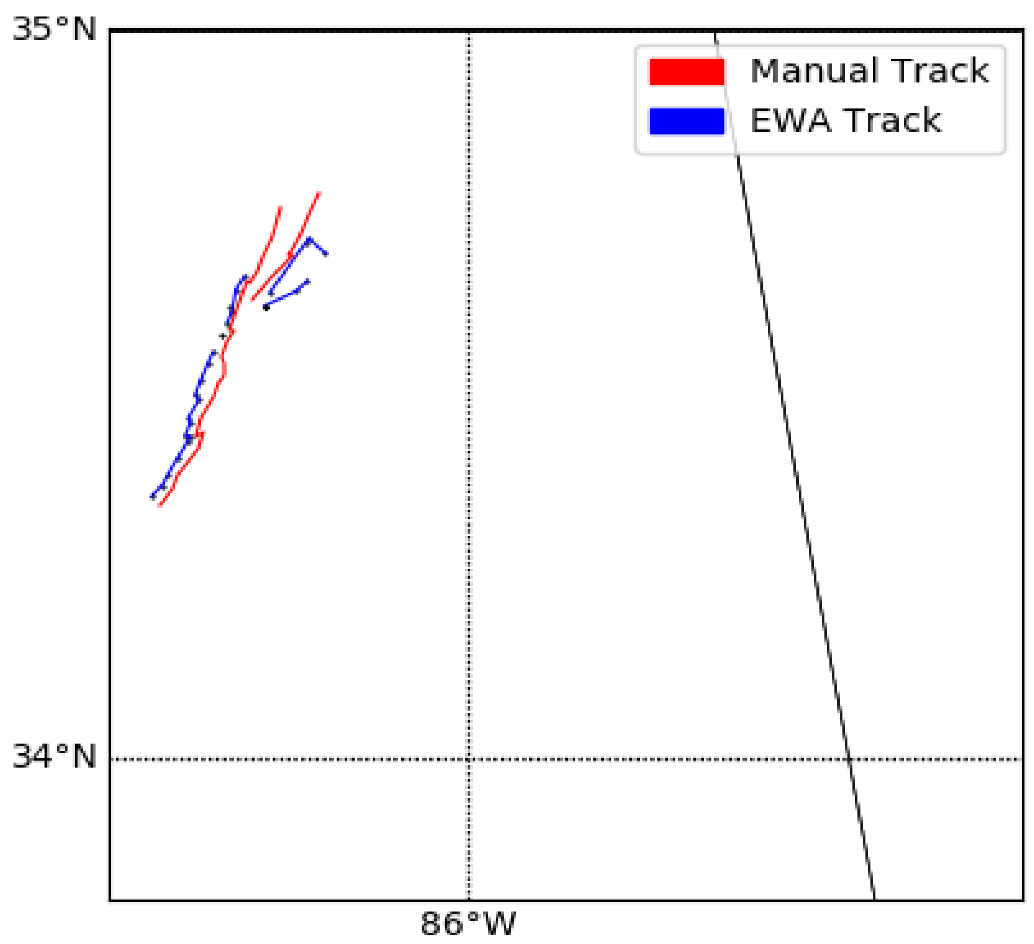


Z_{DR} Hysteresis=1dB Hysteresis=2dB

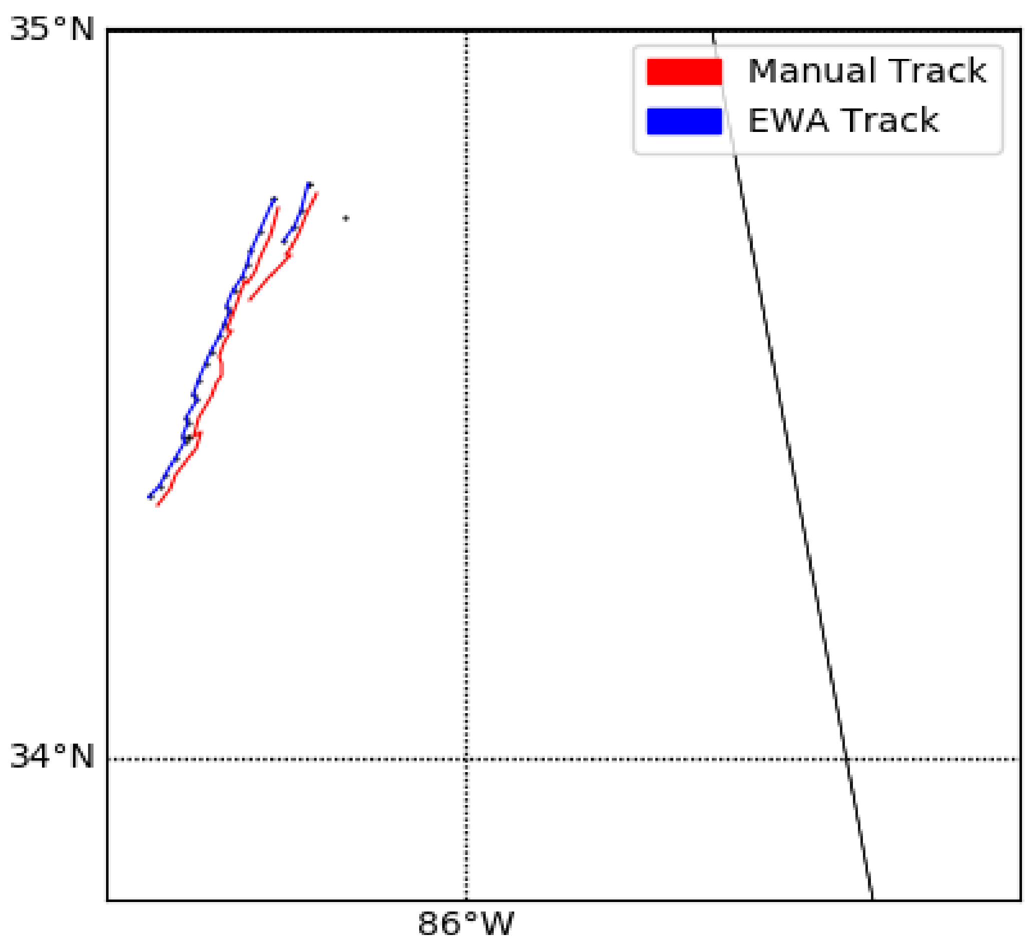
Determining Parameters for EWA and Tracking Algorithm

- A few things to consider when deciding these:
  - Typical areal extent and Z_{DR} values of a Z_{DR} column
  - Limiting identification of spurious data
  - Quality of tracks produced by algorithm
- With this in mind, subjective identification and tracking were done.
  - This was compared to various combinations of parameters in the EWA and tracking algorithm.

Hysteresis=1dB



Hysteresis=2dB



Final Parameter Decisions

- Saliency of 3 km^2
- Hysteresis level of 2 dB
- Increase the search radius by a multiple of two.
  - Search radius is dependent on area of object

Other things that can affect Z_{DR}

- Hydrometeor type (ice vs. liquid)
- Weak returns (very low reflectivity)
- Precipitation concentration **DOES NOT** affect Z_{DR}.

δ

- Can be adjusted to reduce the dynamic range in images.
  - Useful for reducing the number of spurious data with poor spatial resolutions.

Cressman vs. Barnes

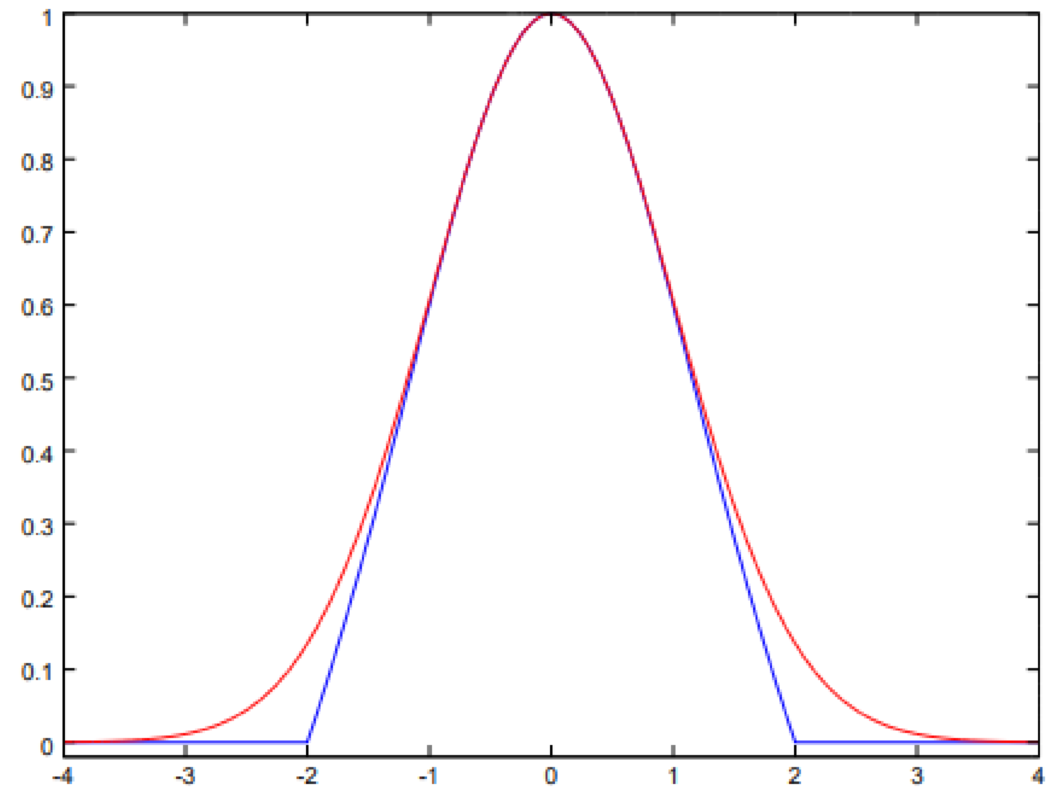
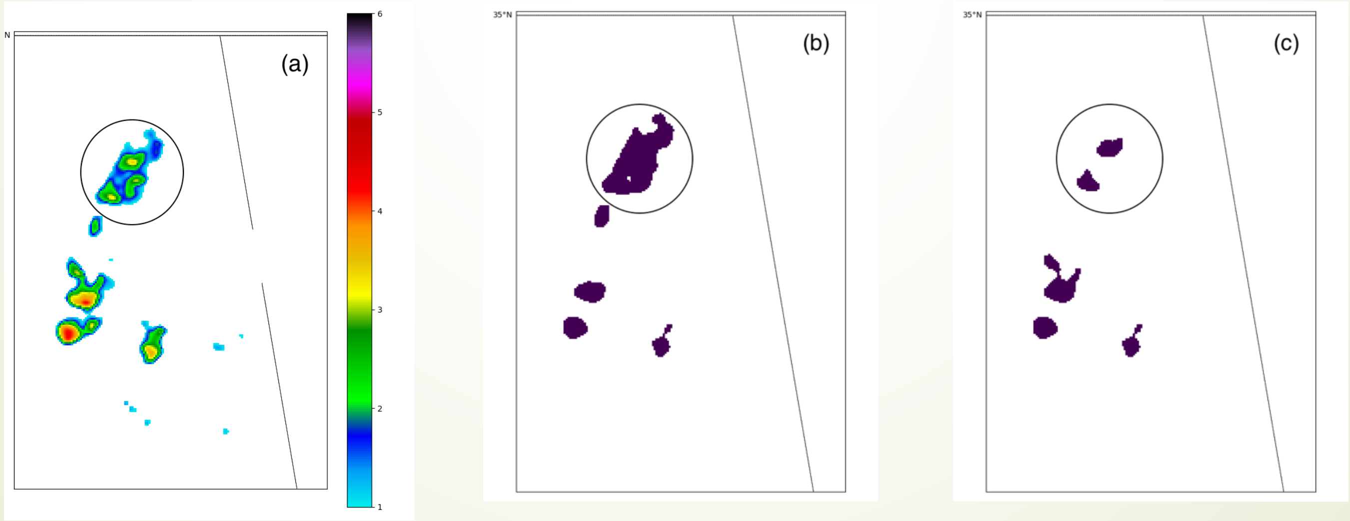


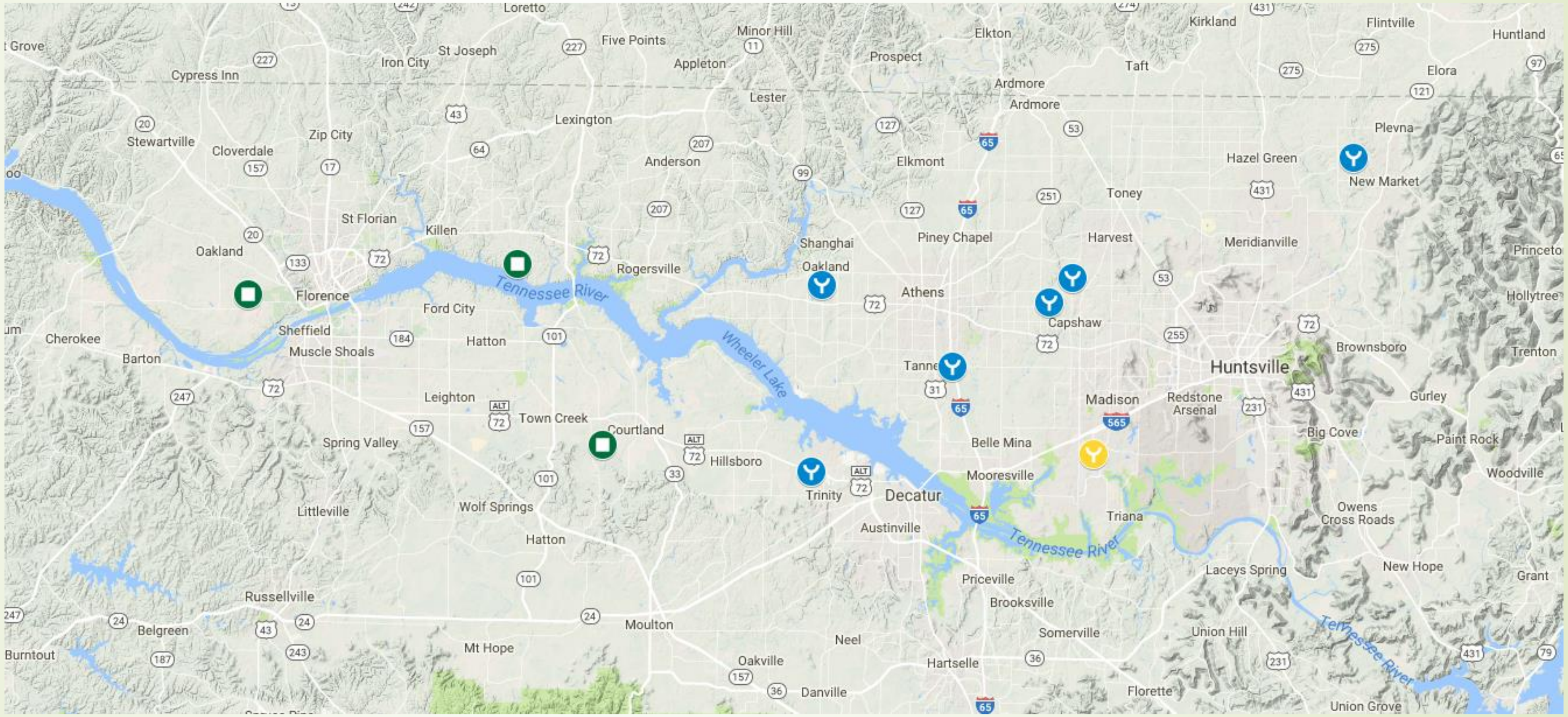
Figure 1.7: Cressman weights for $R = 2$ (blue) and Barnes weights for $R = 1$ (red).

Affecting the scale of identified Z_{DR} columns

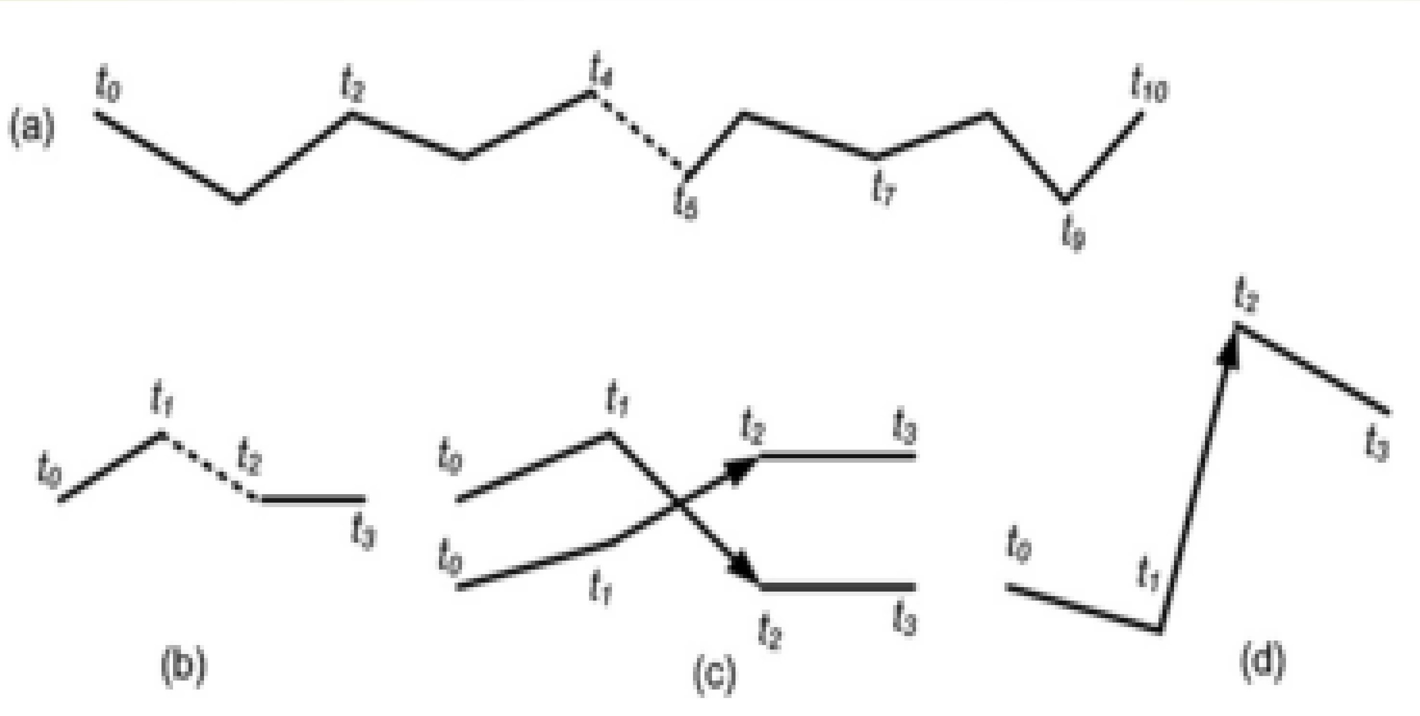
- Hysteresis level (minimum Z_{DR})
- Saliency (minimum areal extent)



Western VORTEX-SE Domain



Errors in Tracks



Cost Function for Tracking Algorithm

- Xi and yi are location coordinates
- Ai is the area
- Di is max pixel value within the cell
- | A | = magnitude

$$c_{i,j} = (x_i - x_j)^2 + (y_i - y_j)^2 + \frac{A_j}{\pi}\left(\frac{|A_i - A_j|}{A_i \wedge A_j} + \frac{|d_i - d_j|}{d_i \wedge d_j}\right)$$

EWA parameter comparisons for identification

Saliency (km²)	2	3	4	5
False Alarms	1	0	0	0
Misses	115	134	168	181
Hits	178	161	146	132
Close	46	30	25	19
POD	0.511	0.463	0.420	0.379
POFD	0.209	0.157	0.146	0.126

Hysteresis = 1 dB

Saliency (km²)	2	3	4	5
False Alarms	34	17	8	7
Misses	21	33	45	58
Hits	220	215	211	202
Close	82	63	67	56
POD	0.632	0.618	0.606	0.580
POFD	0.345	0.271	0.262	0.238

Hysteresis = 2 dB

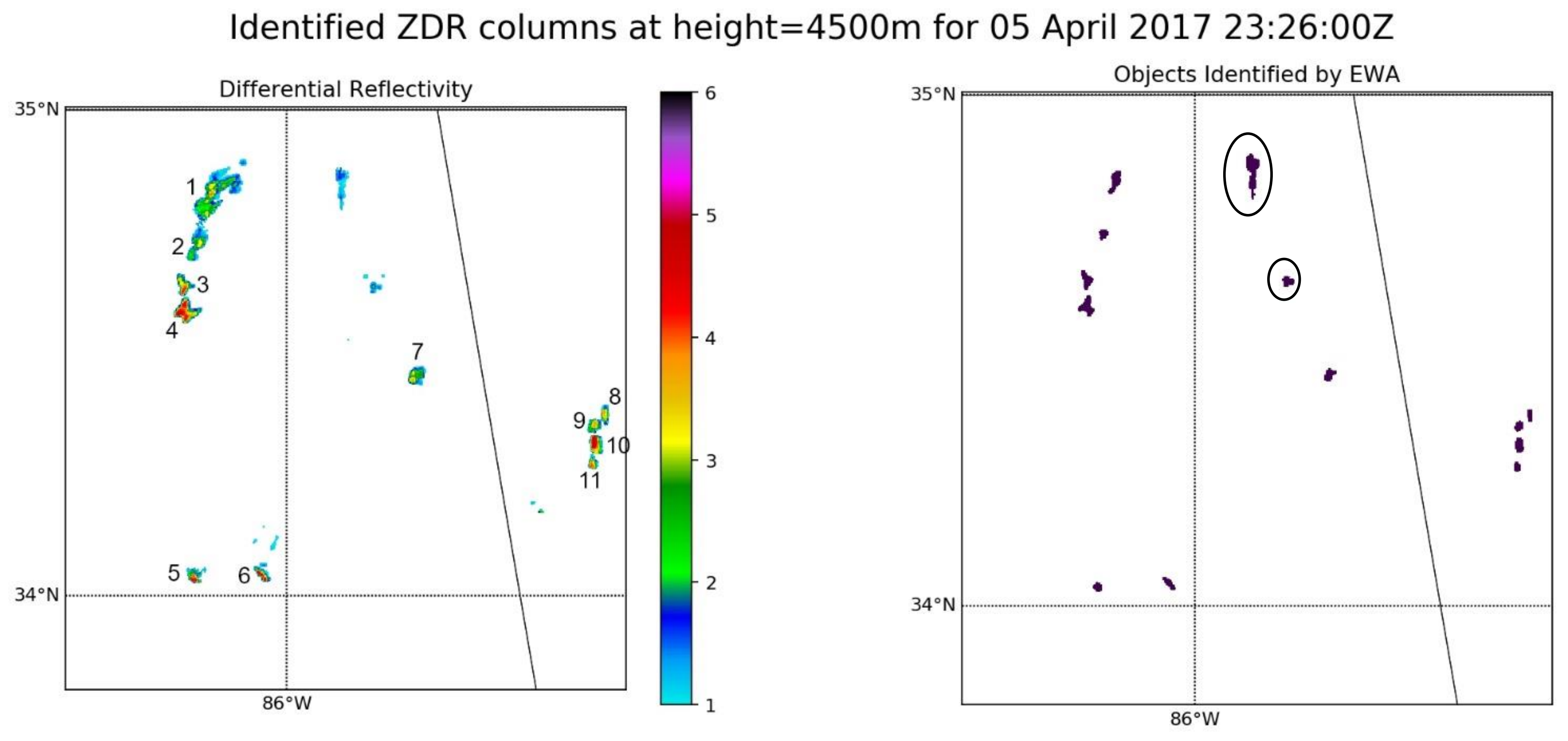
EWA parameter comparisons for tracking

Saliency (km^2)	2	3	4	5
Columns	381	328	304	276
Tracks	74	63	60	53
Average # of Columns per Track	5.14	5.21	5.07	5.21
Average Duration (s)	885	942	888	939
Average Duration (min)	14.75	15.70	14.80	15.65

Hysteresis = 1 dB

Saliency (km^2)	2	3	4	5
Columns	263	221	181	159
Tracks	46	36	30	25
Average # of Columns per Track	5.72	6.14	6.03	6.36
Average Duration (s)	921	1034	1041	1046
Average Duration (min)	15.35	17.23	17.35	17.43

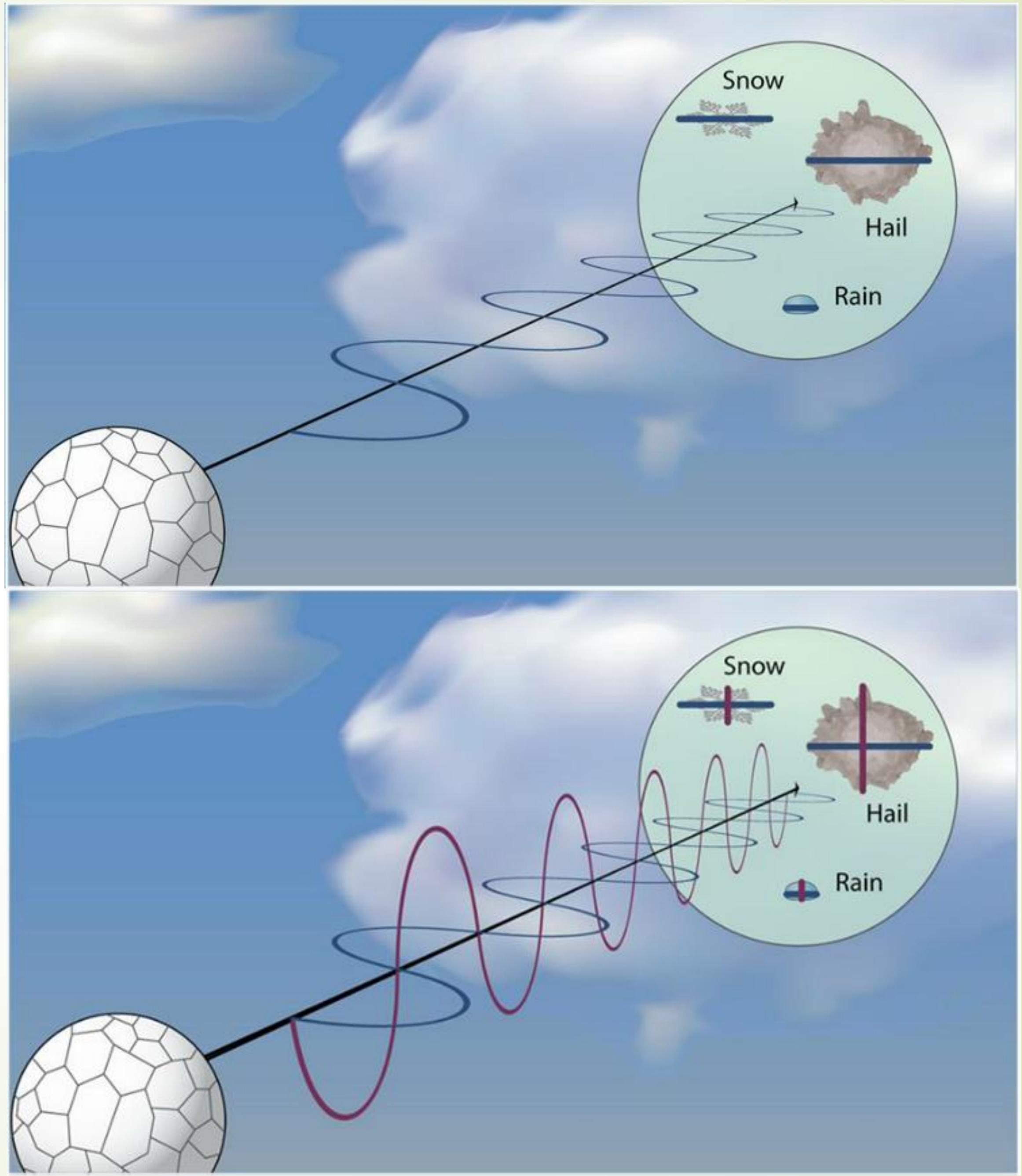
Hysteresis = 2 dB



Identified ZDR columns at height=4500m for 05 April 2017 23:26:00Z
Differential Reflectivity
Objects Identified by EWA
35°N
34°N
86°W
1
2
3
4
5
6
7
8
9
10
11
6
5
4
3
2
1
35°N
34°N
86°W

Polarimetric Radar

- Conventional weather radar transmit waves with a single polarization
- Polarimetric weather radars usually transmit with two orthogonally oriented waves - H/V



Differential Reflectivity (Z_{DR})

- First introduced by Seliga and Bringi (1976)
- $Z_{DR} = \log(Z_H/Z_V)$
  - $Z_{DR} > 0$ for horizontally elongated particles
  - $Z_{DR} < 0$ for vertically elongated particles
  - $Z_{DR} = 0$ for spherical particles

Differential Reflectivity (Z_{DR})

$Z_{DR} > 0$

E.g. rain, wet hail, snow

$Z_{DR} = 0$

E.g. hail, drizzle, snow

$Z_{DR} < 0$

E.g. large hail, pristine ice needles

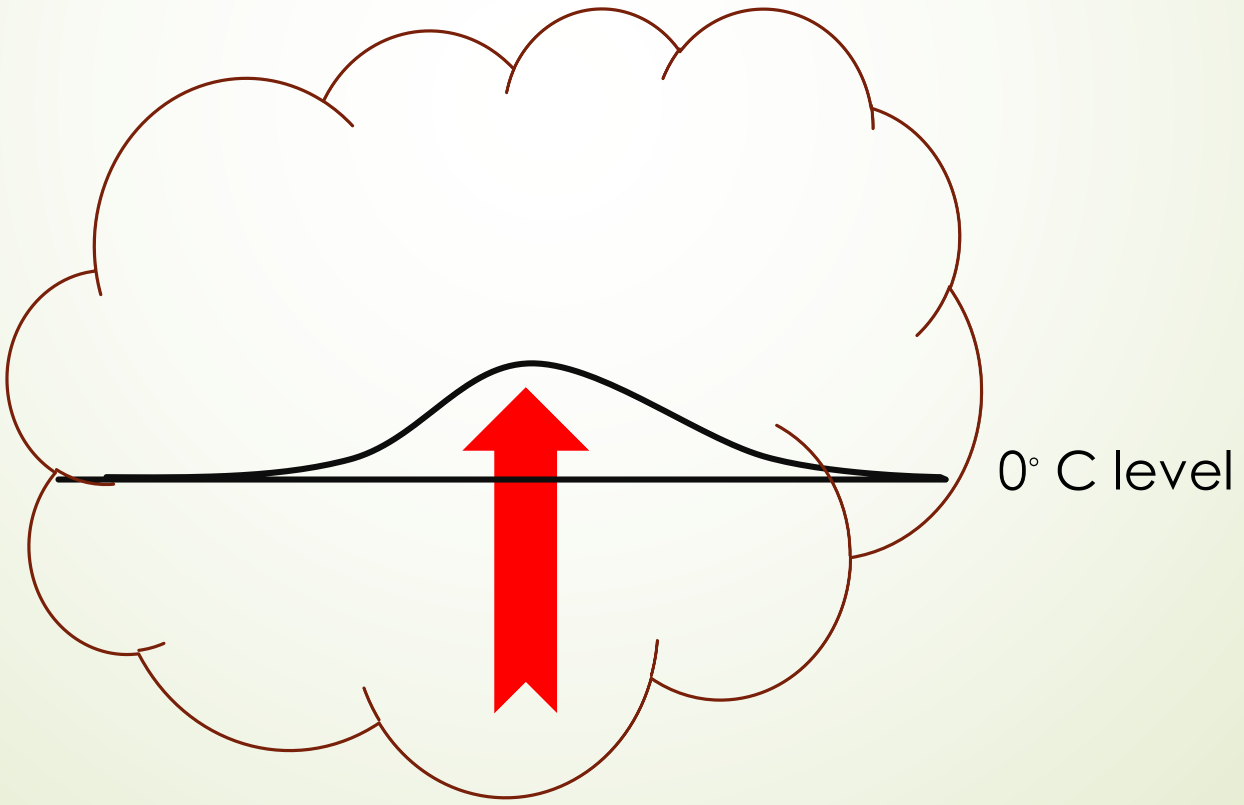
Discerning Hydrometeor Type with Differential Reflectivity (Z_{DR})

- Rain becomes more oblate with size
  - Higher Z_{DR} for larger drops
- Hail can have a variety of Z_{DR} values:
  - Wet hail is usually positive
  - Large hail can be negative
  - Most of the time, near zero though
- Snow close to zero since snow has very low density and ice in general has lower Z_{DR} values.

Z_{DR} Columns – How are they formed? Why do they occur?

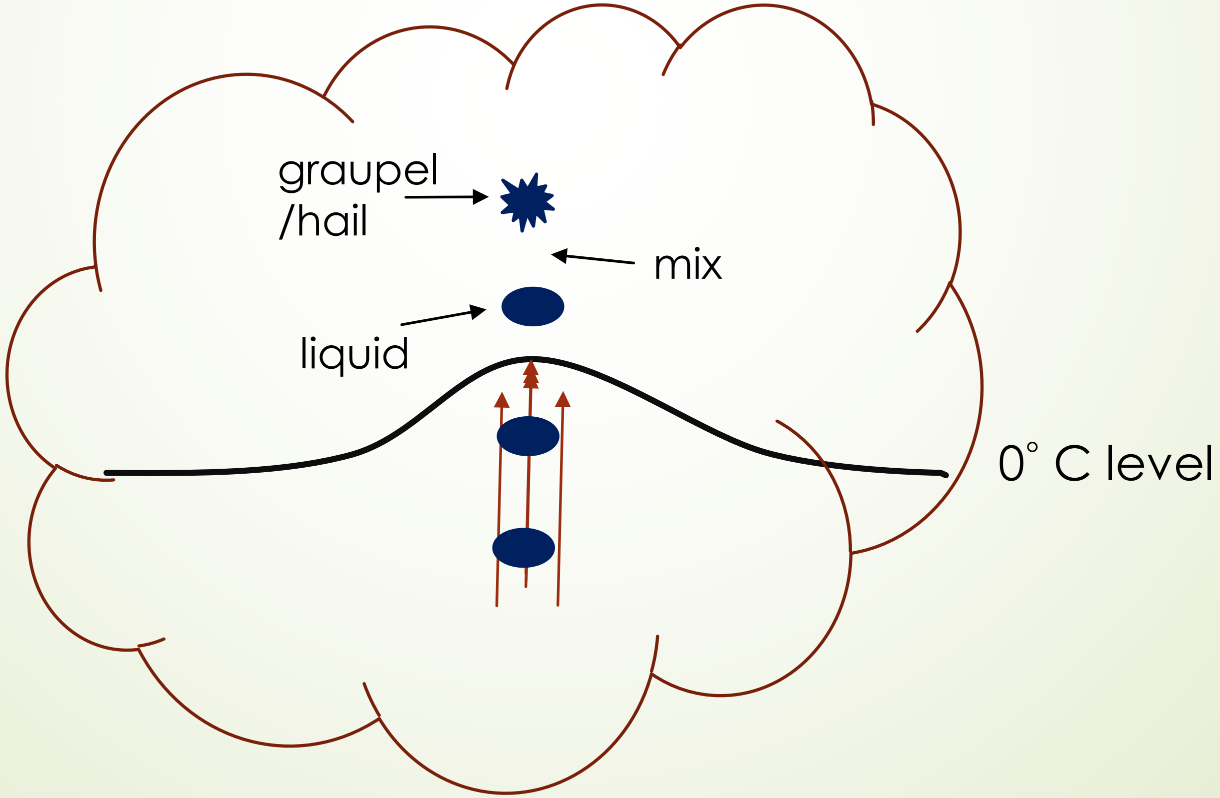
Two reasons for raindrops above freezing level in updraft:

1. Positive temperature perturbation in updraft



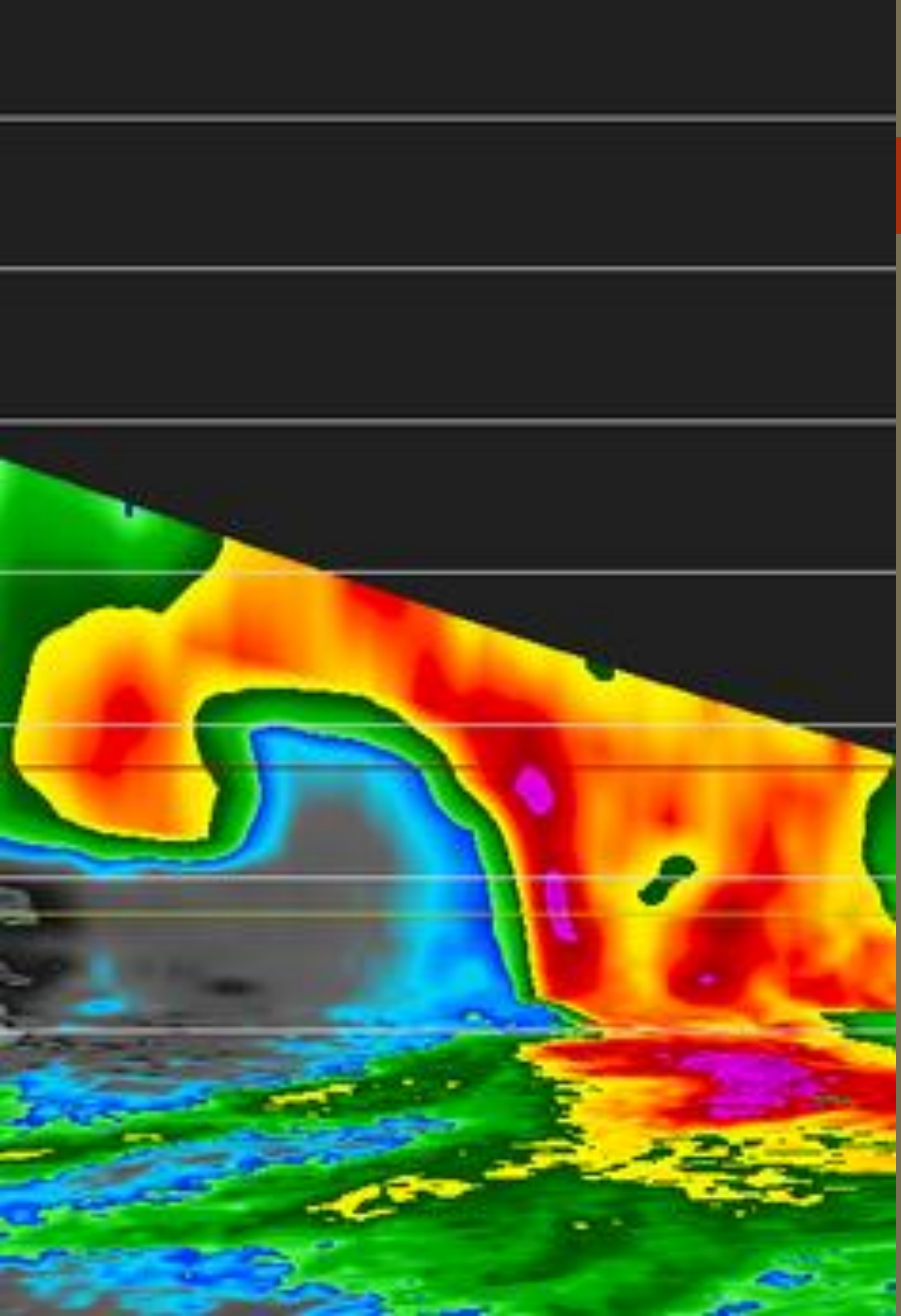
Two reasons for raindrops above freezing level in updraft:

2. It still takes several minutes for a drop to freeze upon entering subfreezing temperatures



Z_{DR} Columns – so what?

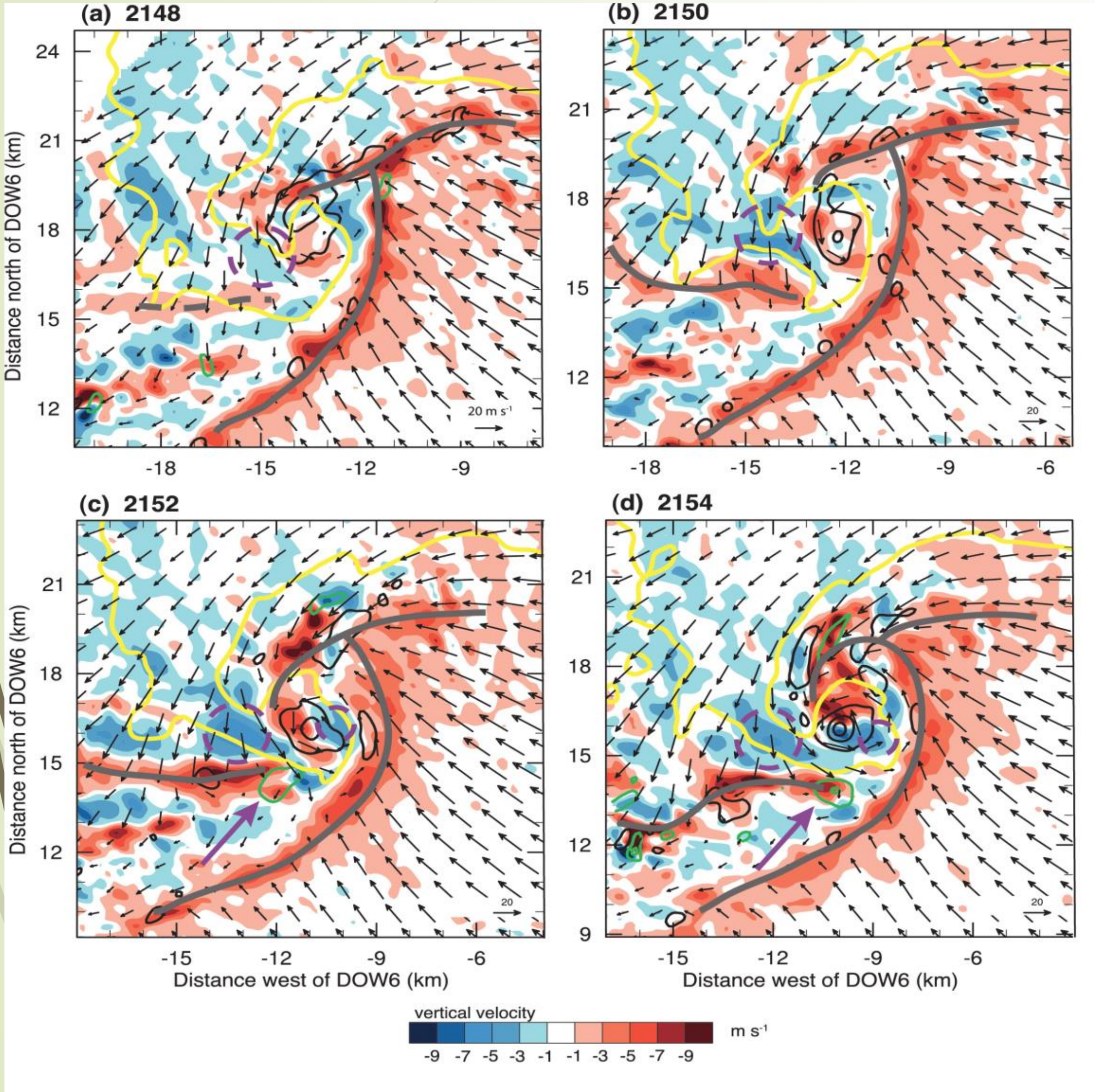
- There are other ways to identify the updraft region in radar data:
    1. Bounded weak echo region (BWER)
    2. Retrieve vertical velocities from dual doppler analysis



Z_{DR} Columns – so what?

1. Bounded weak echo region (BWER)
   - BWER are defined as a "minima" making it difficult to automatically identify
   - They only appear in supercells with strong updrafts.
   - Z_{DR} columns on the other hand, are maxima, which is much easier to automatically identify
   - Z_{DR} columns are also apparent in almost all thunderstorms and are much more common than BWER.

Z_{DR} Columns – so what?



2. Retrieve vertical velocities from dual doppler analysis
   - Require multiple radars to retrieve and are harder to obtain
   - Z_{DR} columns can be observed by a single radar

Kosiba and Wurman (2013)