Dual Polarization Radar Interpretation, Applications and Examples

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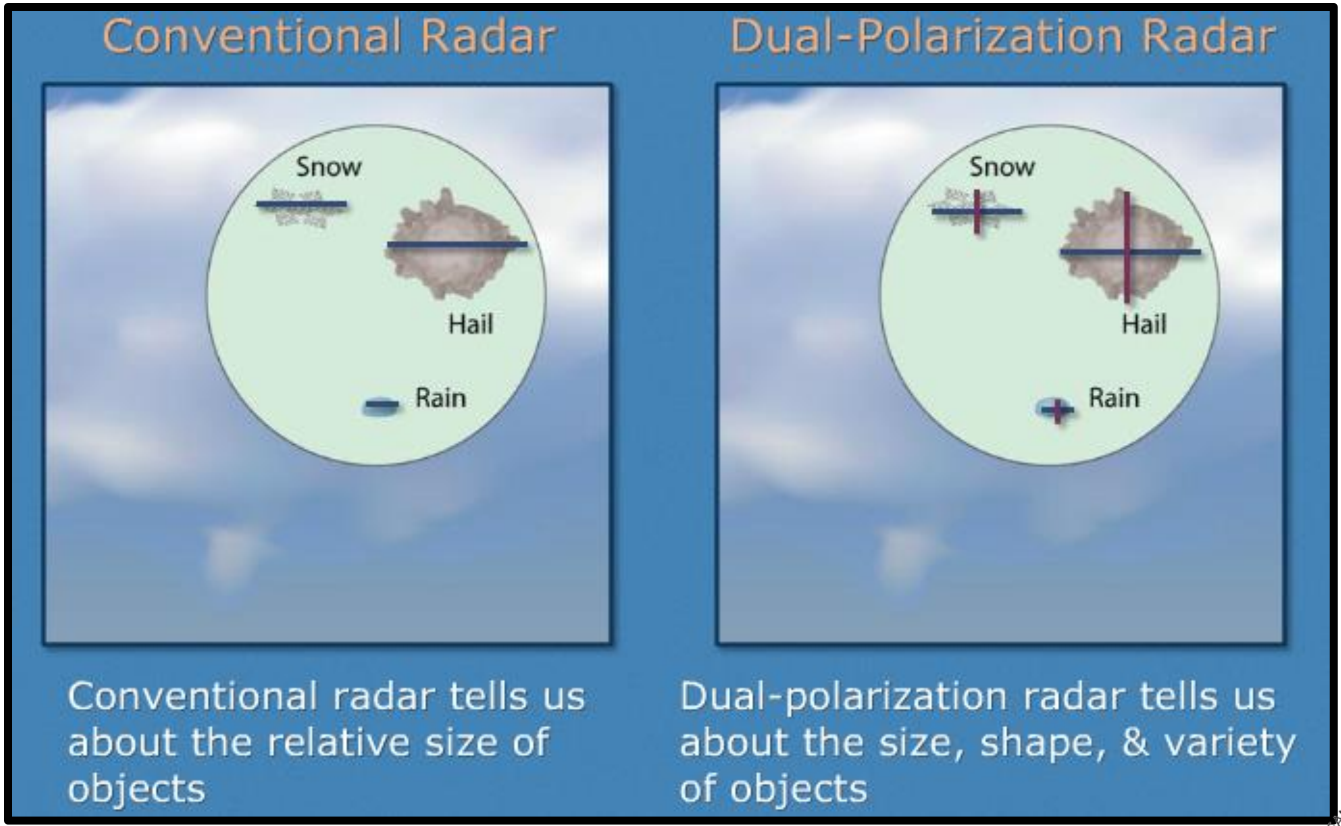
Outline

- Conventional vs. Dual Pol radars (differences)
- Dual Polarization base products, uses, and examples
  - Differential Reflectivity (Z_{DR})
  - Correlation Coefficient (CC)
  - Specific Differential Phase (K_{DP})
- Dual Pol Algorithm/Derived product: (Hydrometeor Classification Algorithm)

Dual Polarization Radar

- The KENX radar was upgraded to Dual-Pol: 23-27 April 2012
- The radar now has the ability to transmit and receive both horizontal and vertical pulses
- Helps forecasters gain more info. about particle (droplet) size and distribution and helping to more accurately determine precipitation type and rate

Difference between Conventional WSR-88D Radar & Dual-Pol Radar

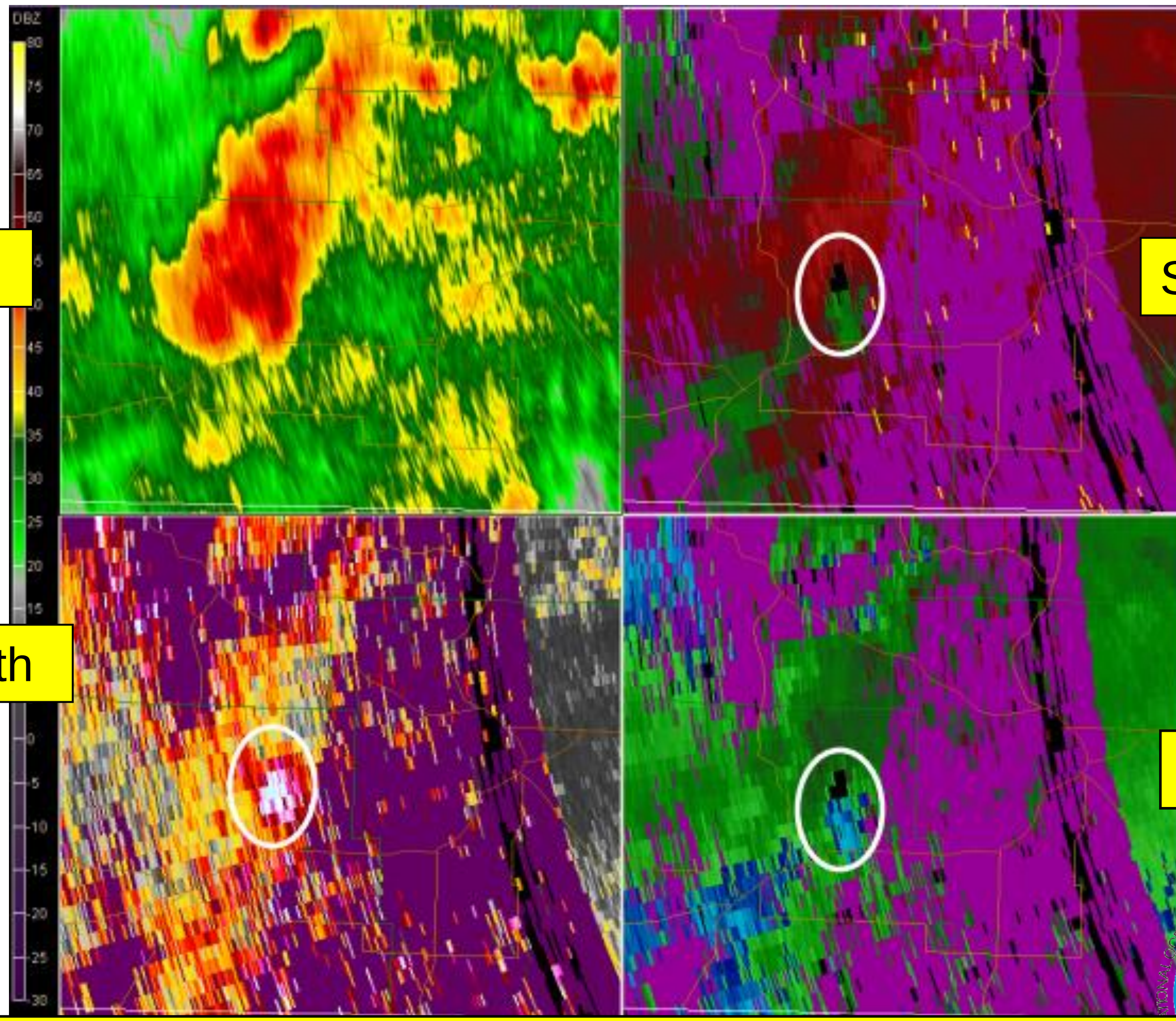


Impacts of Dual-Pol Radar

- We still receive the 3 legacy base products
  - Reflectivity (in the horizontal), Velocity and Spectrum Width (determines turbulent flow)
- The Dual Polarization Radar now gives us 3 brand new additional base products
  - Also, several new derived and precipitation products as well (We will not have time to review Precip/QPE products in great detail)
- Gives us more physical data to use during storm interrogation (Warm and Cool season) for Warning Decision Making

Spectrum Width Severe Example

May 2, 2010 Distant supercell example



EF-0 tornado tied to circulation in white circle is 10-15 mins before touchdown. Spectrum width showed high values due to turbulent flow.

Dual Pol Base Products

- Differential Reflectivity (Z_{DR})
- Correlation Coefficient (CC)
- Differential Phase (Φ_{dp})
  - We will use this product as Specific Differential Phase (K_{DP})

Info. Dual Polarization Products:
https://training.weather.gov/wdtd/courses/rac

Z_{DR} – Differential Reflectivity (dB)

Definition

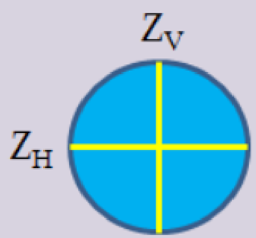
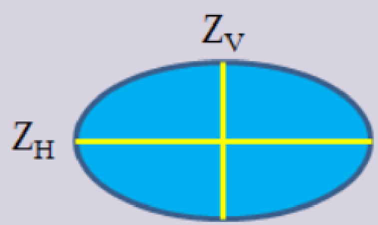
- Difference between the horizontal and vertical reflectivity factors (in dB units)

$$ZDR = Z_H - Z_V$$

$$Z_{DR} = 10\log\left(\frac{\langle S_{hh}^2 \rangle}{\langle S_{vv}^2 \rangle}\right)$$

- Z_{DR} is a ratio of the horizontal and vertical power returns
- Z_{DR} will give the forecaster a good idea of the mean droplet size and shape

Z_{DR} (dB) Interpretation

Spherical (drizzle, small hail, etc.)	**Horizontally Oriented** (rain, melting hail, etc.)	**Vertically Oriented** (i.e. vertically oriented ice crystals)
		
$Z_H \sim Z_V$	$Z_H > Z_V$	$Z_H < Z_V$
$Z_H - Z_V \sim 0$	$Z_H - Z_V > 0$	$Z_H - Z_V < 0$
ZDR ~ 0 dB	ZDR > 0 dB	ZDR < 0 dB

Key: Indicator of dominant drop shape

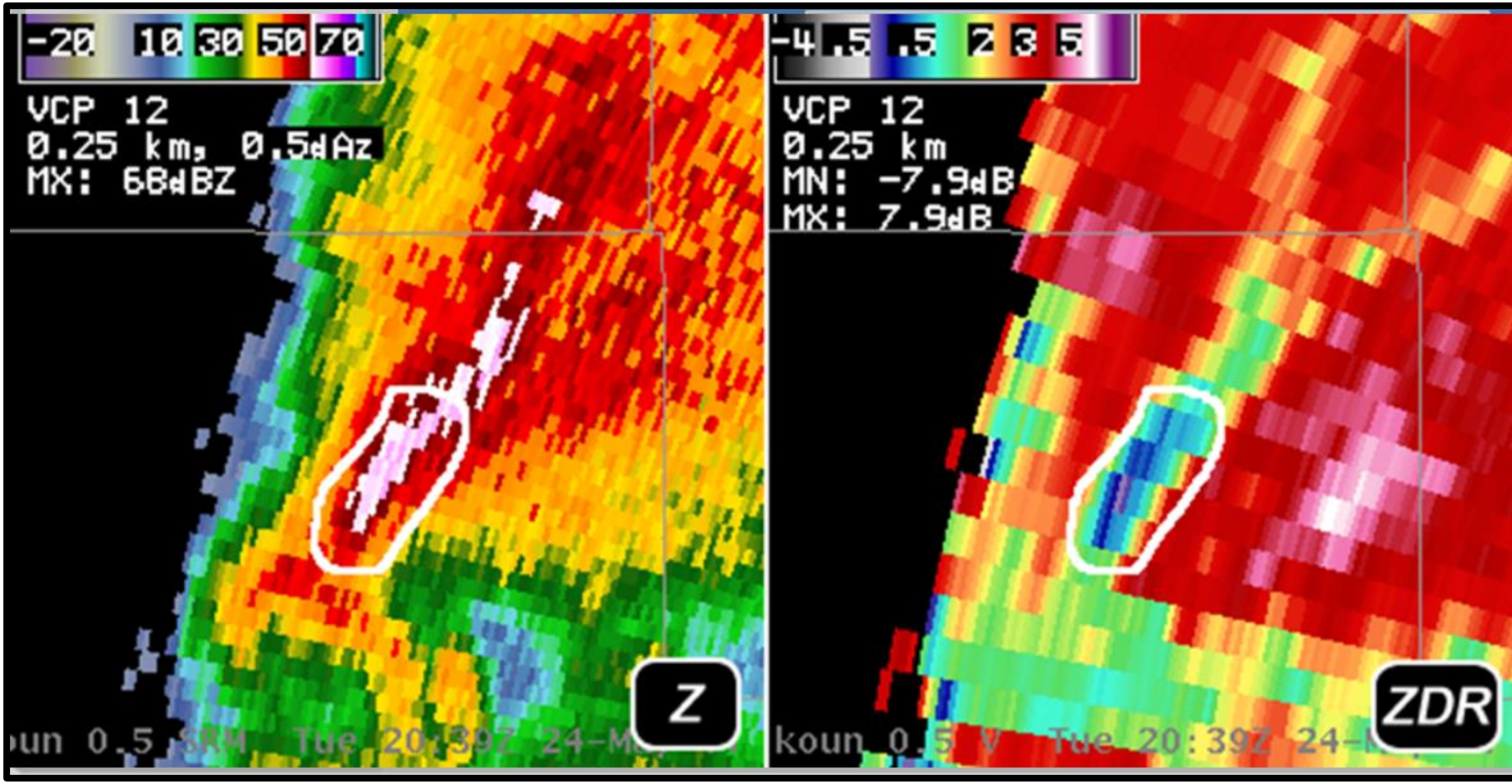
Z_{DR} (dB) for Rain

Direct Relationship: The larger the droplet size, the larger the ZDR

Major Axis Diameter (mm)	Image	ZDR (dB)
< 0.3 mm		~ 0.0 dB
1.35 mm		~ 1.3 dB
1.75 mm		~1.9 dB
2.65 mm		~2.8 dB
2.90 mm		~3.3 dB
3.68 mm		~4.1 dB
4.00 mm		~4.5 dB

https://training.weather.gov/wdtd/courses/rac/products/zdr

Z_{DR} (dB) for Hail



- Hail has a high Z (dBZ) and low ZDR (~0 dB), especially if falling or tumbling
- Small hail that is melting has a high ZDR, like giant rain drops (5-6 dB's)

Z_{DR} (dB) for Snow or Ice

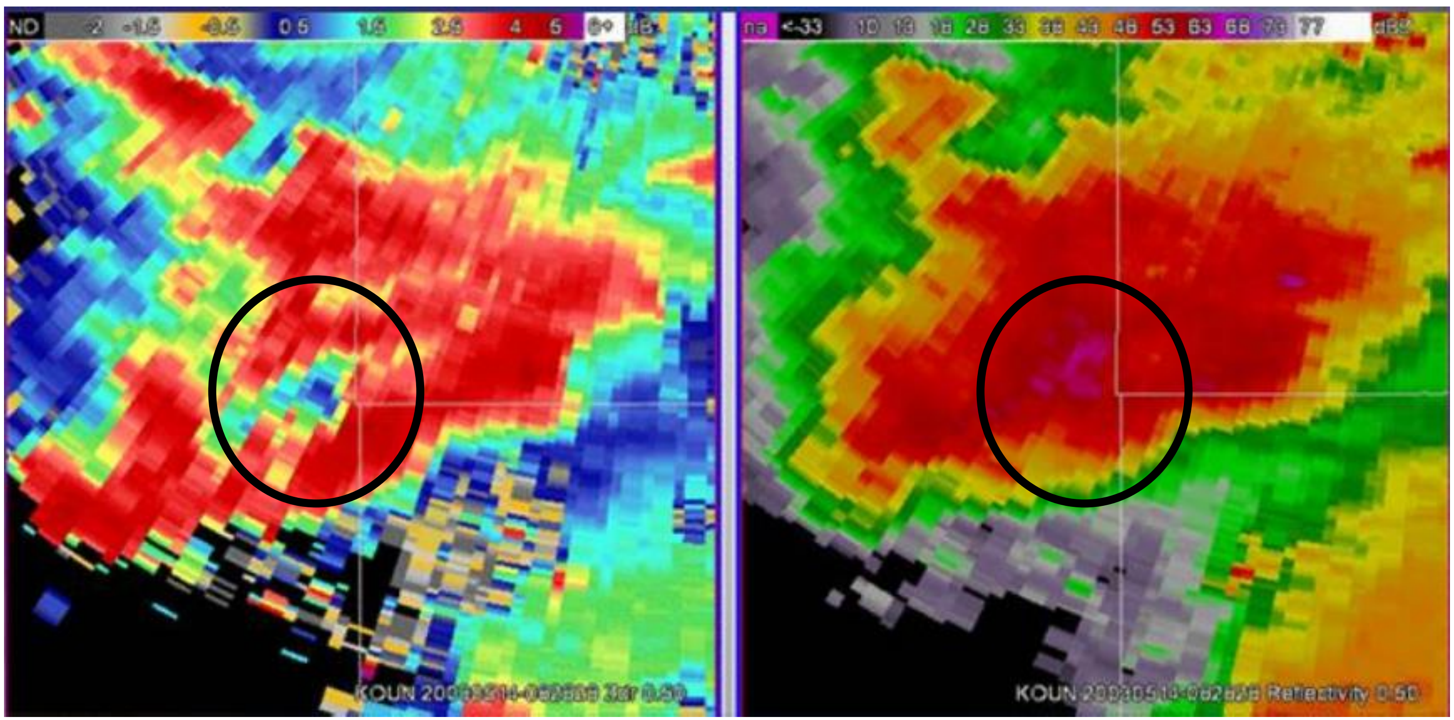
Interpretation is more involved :
- Wet or dry snow?
- Low or high density?
- What is the preferred orientation?

Snow	ZDR
Dry / Aggregated	0.2 to 0.3 dB
Wet / Melting	2 to 3 dB
Ice	**ZDR**
Low-density / Random orientation	< 1 dB
High-density / Preferred Orientation (Horizontal)	As high as 4 to 5 dB
High-density / Preferred Orientation (Vertical)	- 2 to 0 dB

Z_{DR} Uses/Applications

- Locations of hail shafts if the Z_{DR} ~ 0 dB (near spherical hydrometeors) coincident with high Z (REF)
- Z_{DR} much greater than 0 dB indicates large rain drops
- Identification of strong updraft area in thunderstorms (Z_{DR} columns) with liquid drops well above freezing/melting Layer
- Determination of Wet vs. Dry Snow in Cool Season
- Areas of small hail mixed with rain could have high Z_{DR} (water covered hail stones)

Severe Weather Example of Z_{DR} for a Supercell



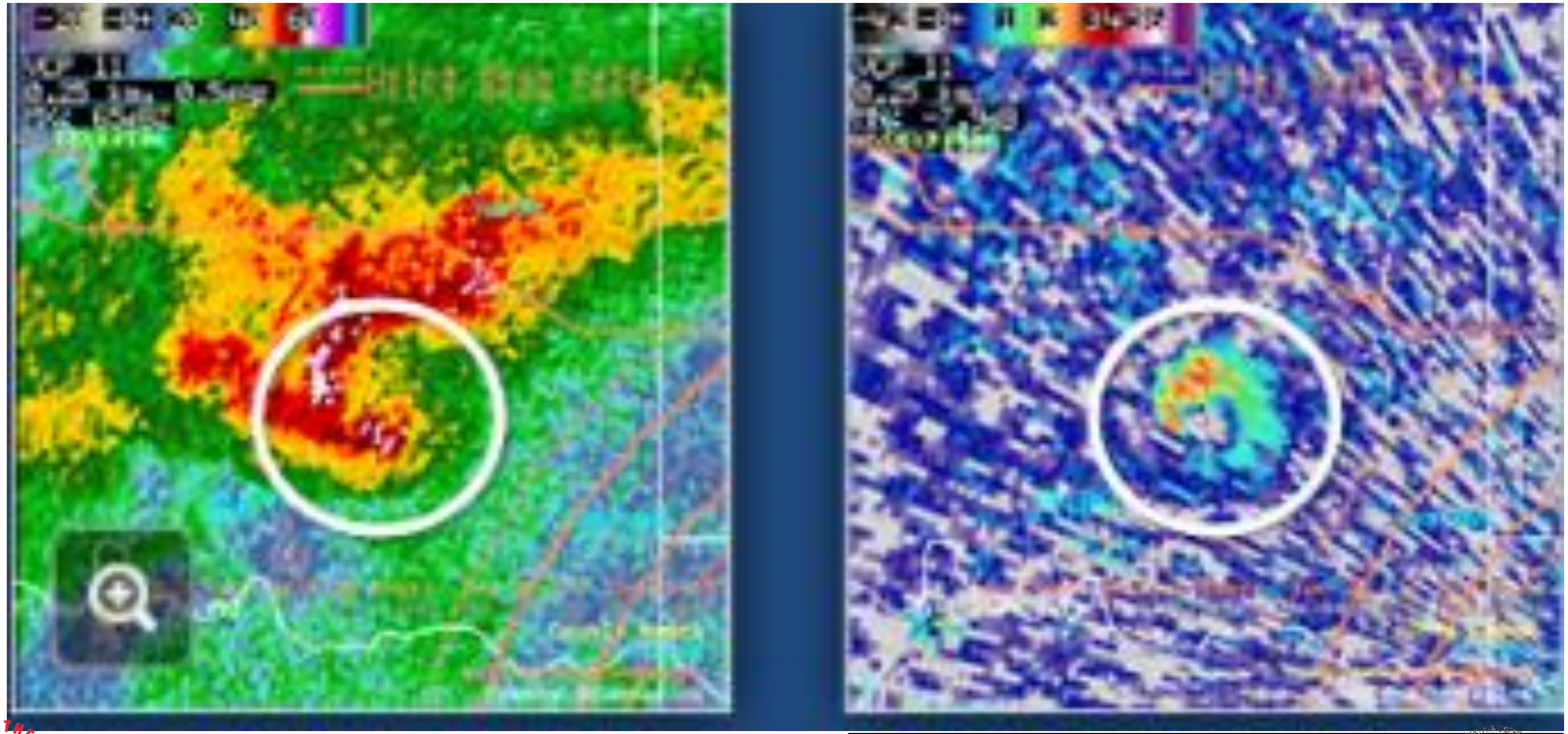
Differential Reflectivity (Z_{DR})

Reflectivity (Z)

Values of Z_{DR} near zero along with high values of Z indicate a hail shaft.

Z_{DR} Applications/Uses: ZDR Columns

ZDR Columns: strong/intense updraft identification
ZDR is usually > 1 above the melting layer/freezing layer
Brian F. will review more examples in the next presentation

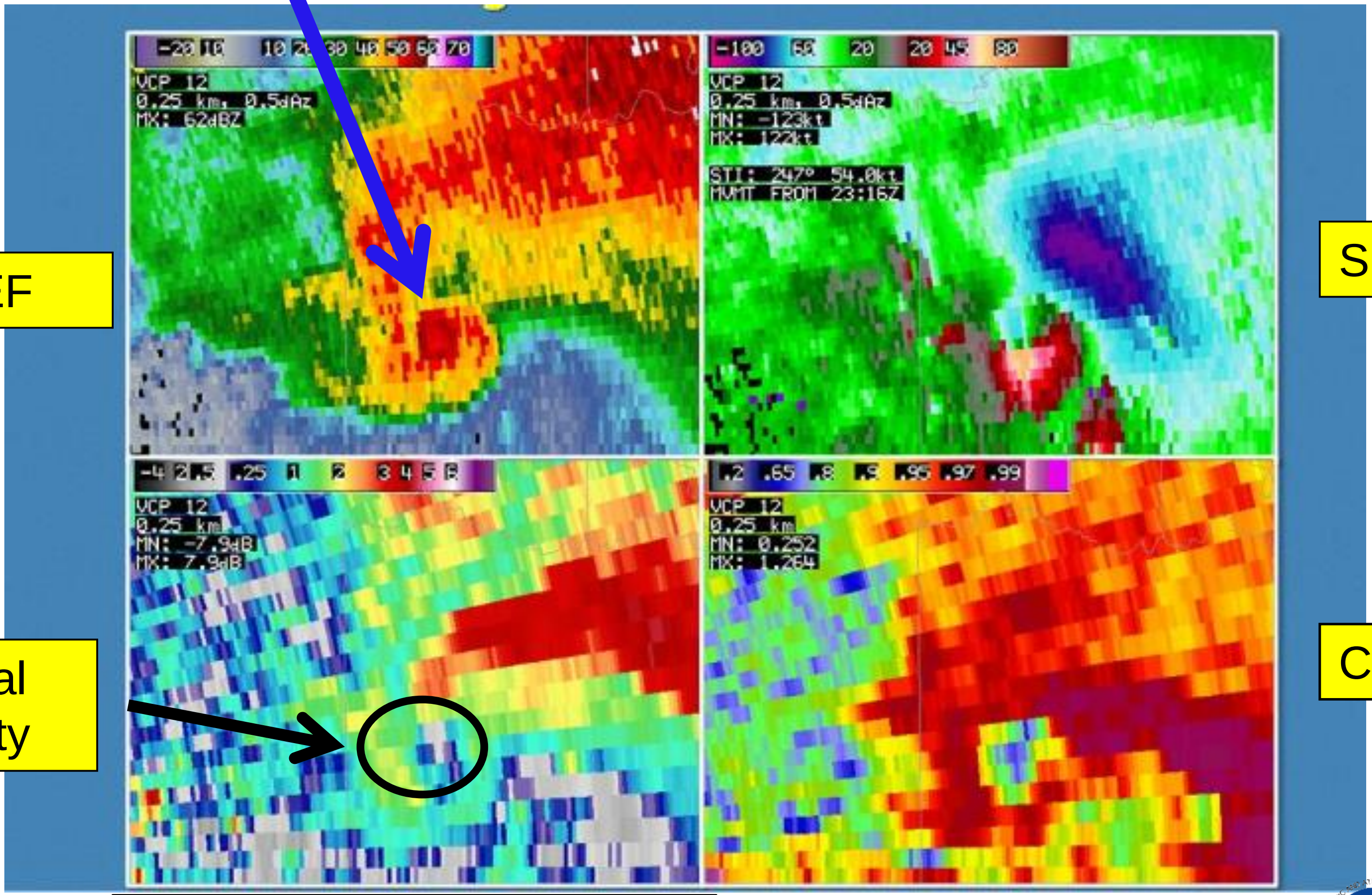


High Z (dBZ) above the FZL

ZDR greater than > 1 dB above

Tornadic Debris Signature (TDS) Use

Insulation and shingles lofted



Base REF

SRM

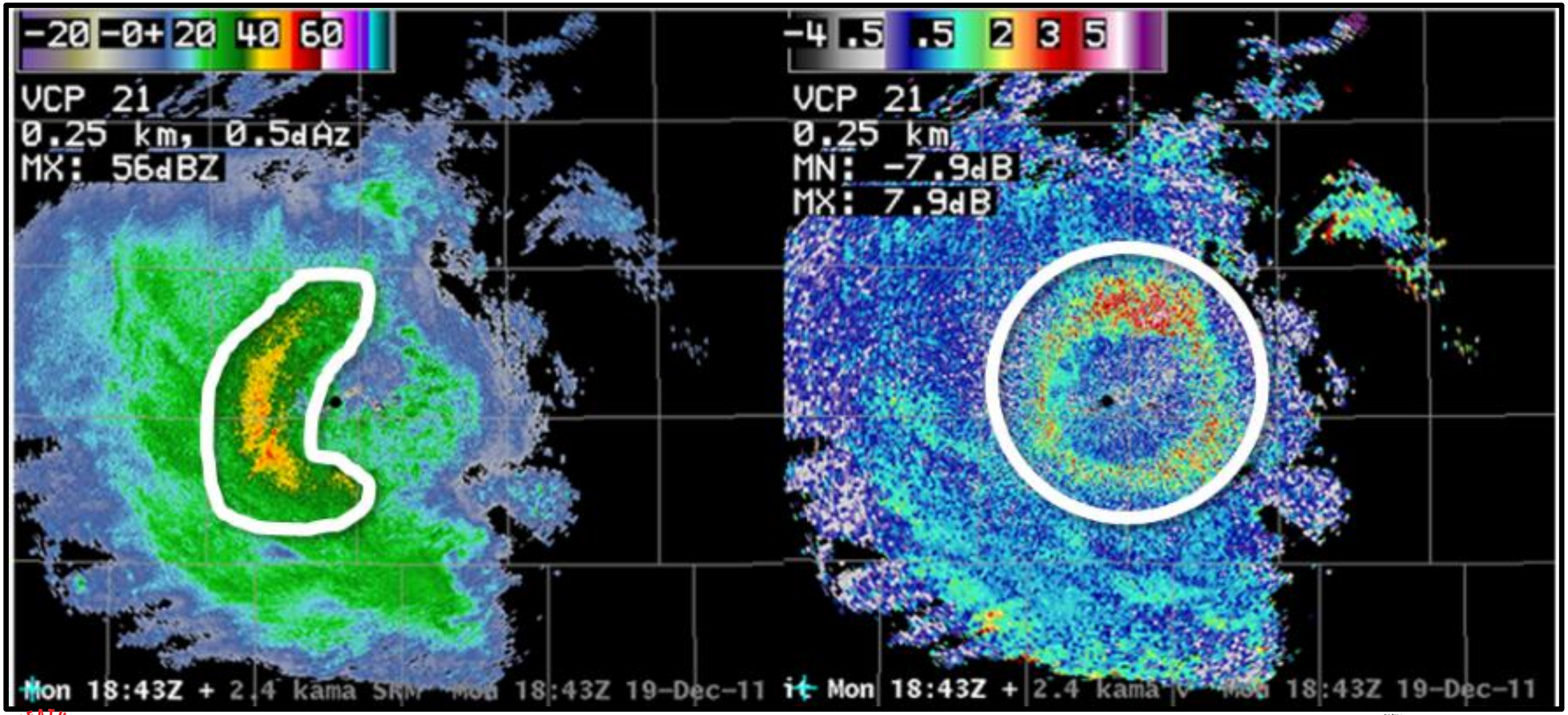
Differential Reflectivity

Corr. Coeff

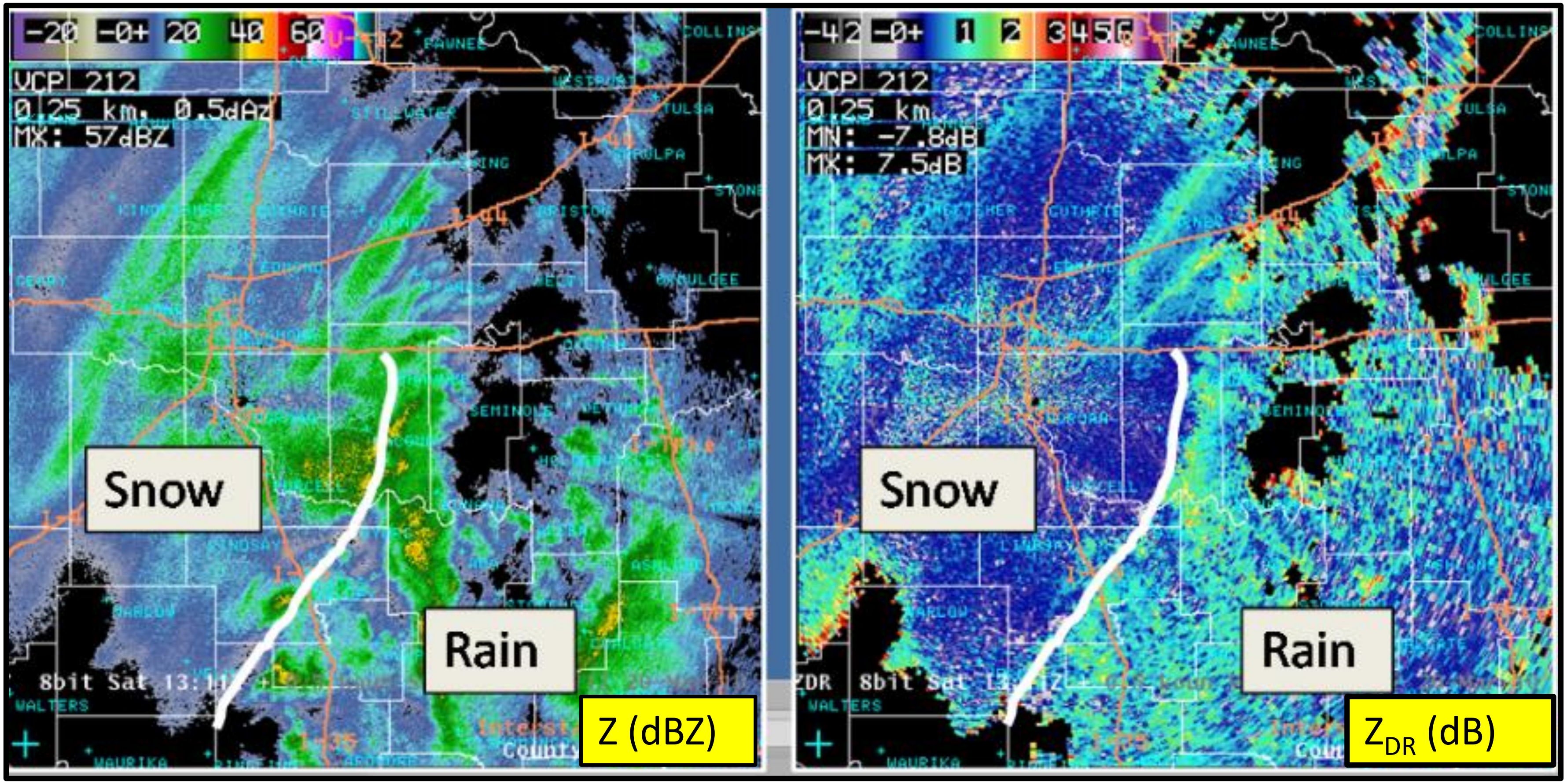
Low Z_{DR} ~ 0 dB in area of possible tornado

Melting Layer Identification

- Identified as region of high Z_{DR} (dB)



Rain vs Snow Usage (Z_{DR})



Rain vs Snow lines or transition zones: (1) Rain area – > ZDR > 1 dB
(2) Snow area – > ZDR ~ 0 dB

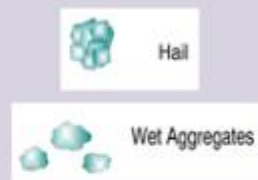
Correlation Coefficient (CC)

- A measure of the correlation between the horizontal and vertical back-scattered pulses from the scatterers within a sample volume scan of the radar (some similarities to spectrum width)
- Mathematically known as $\rho_{hv \text{ (unit less)}}$
- Can determine precipitation type, meteorological vs. non-meteorological echoes

CC Interpretation Table

*** Hydrometeors more uniform with high CC values in the right column**

Han Carbonite –
Non-met target (sort of)

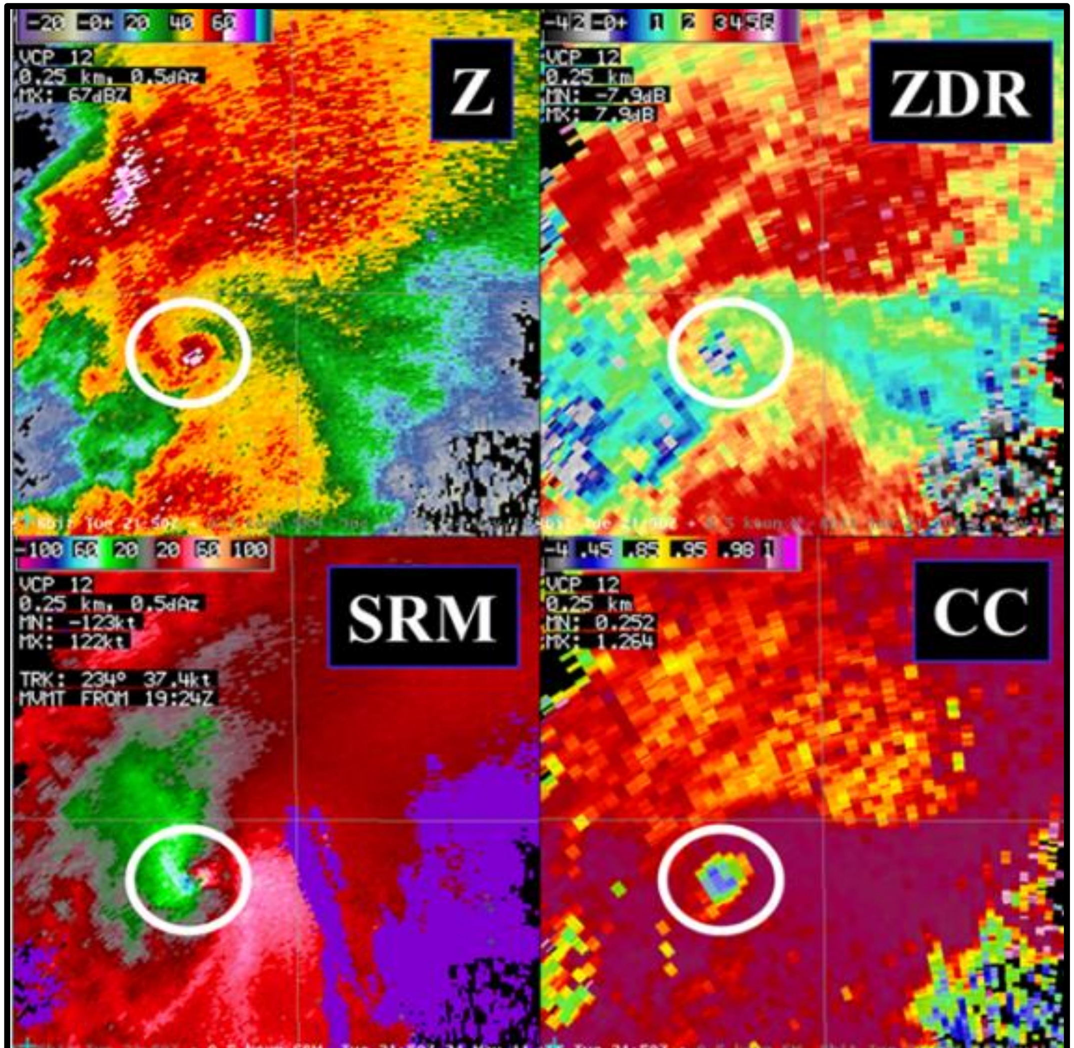
Non-Meteorological (birds, insects, etc.)	Metr (Non-Uniform) (hail, melting snow, etc.)	Metr (Uniform) (rain, snow, etc.)
		
Complex scattering from pulse-to-pulse.	Somewhat complex scattering from pulse-to-pulse.	Well-behaved scattering from pulse-to-pulse.
Low CC (< 0.8)	**Moderate CC (0.80 to 0.97)**	**High CC (> 0.97)**

Correlation Coefficient

- Values > 0.97 indicate a consistent size, shape, orientation, and/or phase of hydrometeors
- CC 0.80 to 0.97 indicates a mixture of the size, shape, and orientation and/or phase of hydrometeors
- CC < 0.80 is usually non-meteorological scatterers (birds, insects, buildings) and sometime large hail

Values of greater than 1.00 are possible in areas of noisy data at a far range and low SNR (signal to noise ratio) and these values should just be ignored.

CC Uses/Applications: TDS



Z > 30 dBZ

ZDR ~ 0 dB

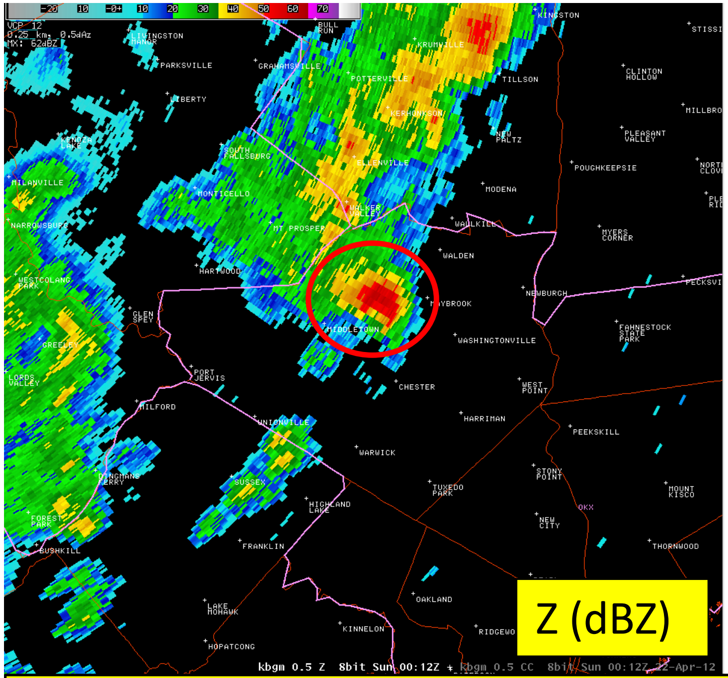
Tornadic velocity couplet in SRM

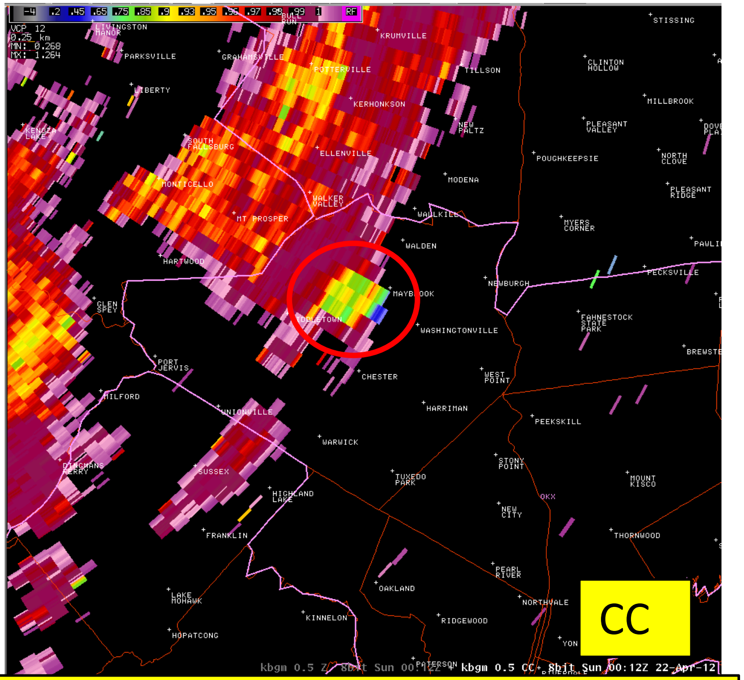
CC < 0.80

Tornadic Debris Signature (TDS) has low CC due to shingles, leaves, and other non-meteorological debris lofted

CC Uses/Applications: Severe Hail

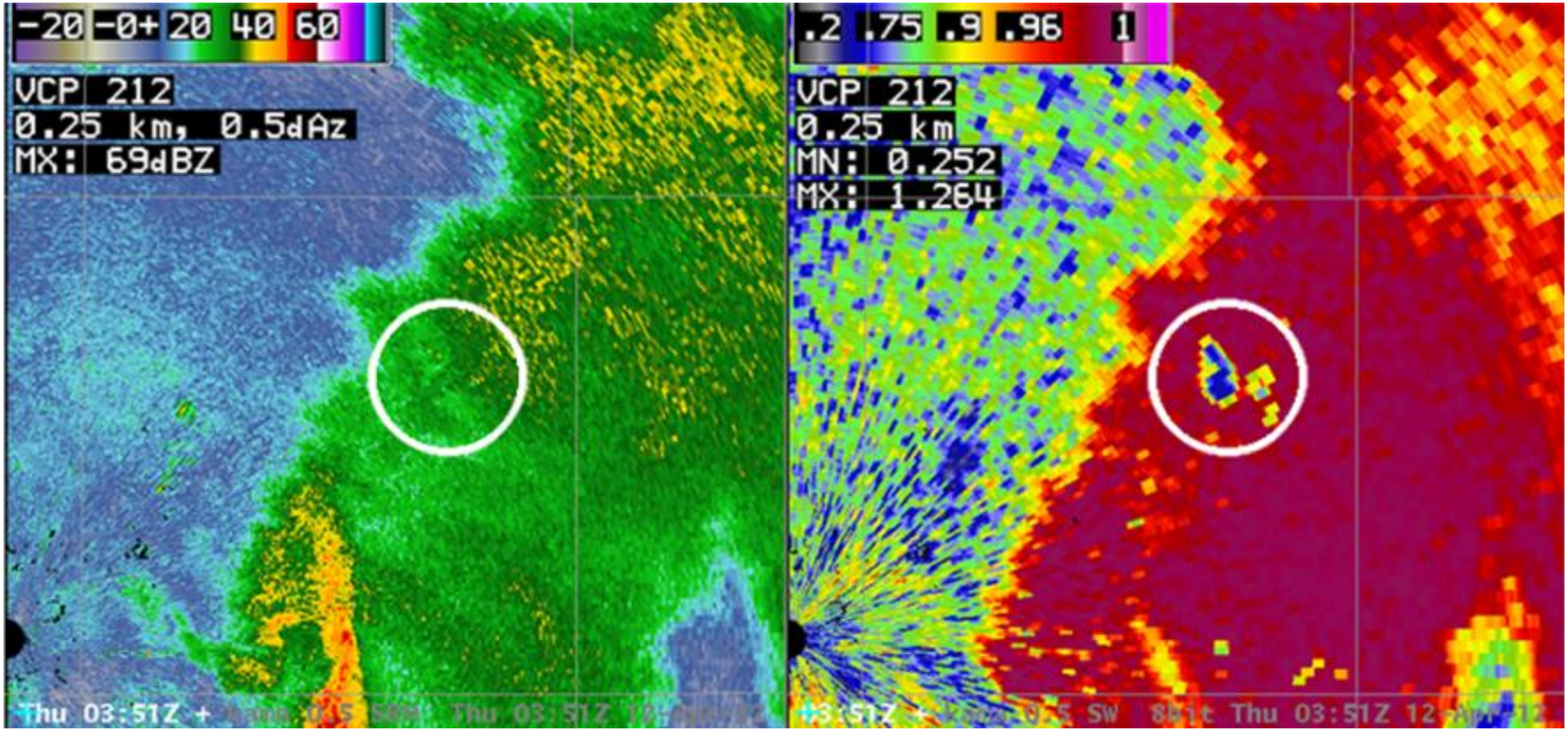
Severe Hail Guidance: (1) CC < 0.90 is 2"+ diameter hail
(2) CC < 0.75 can be large, spiky hail





Radar images from KBGM from the evening of April 21, 2012 with Z (REF) on the left and CC (Correlation Coefficient) on the right. Notice the area of lower CC values (0.85-0.90) along with high Z values indicate hail aloft.

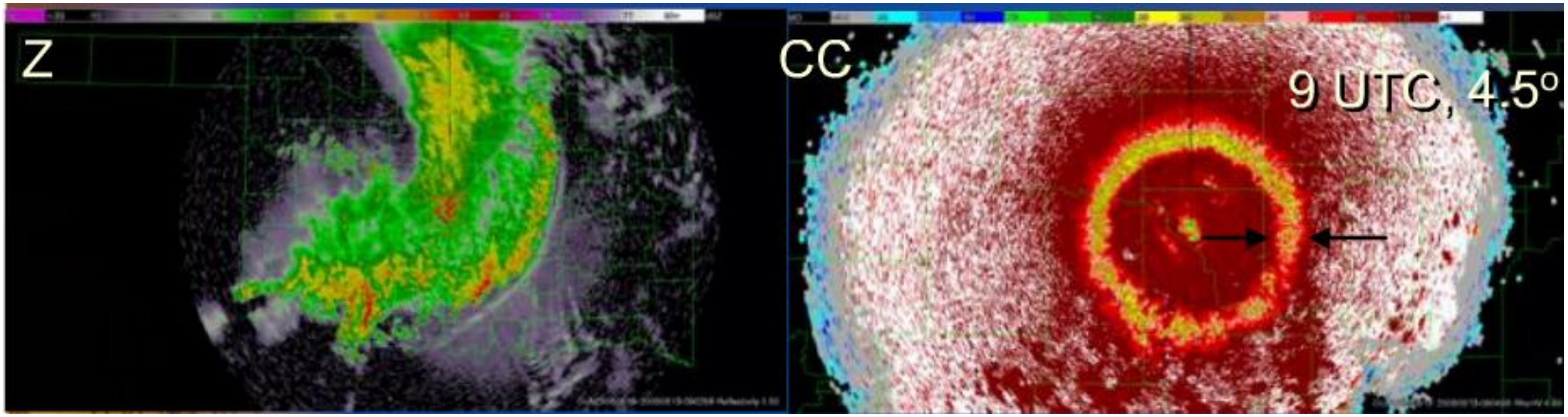
CC Uses/Applications: Meteorological vs. non Meteorological Echoes



General rain, but a tower or some non-meteorological target picked up.
Recall: CC > 0.80 meteorological targets, and CC < 0.80 non-meteorological echoes.

CC Use/Applications: Melting Layer Detection

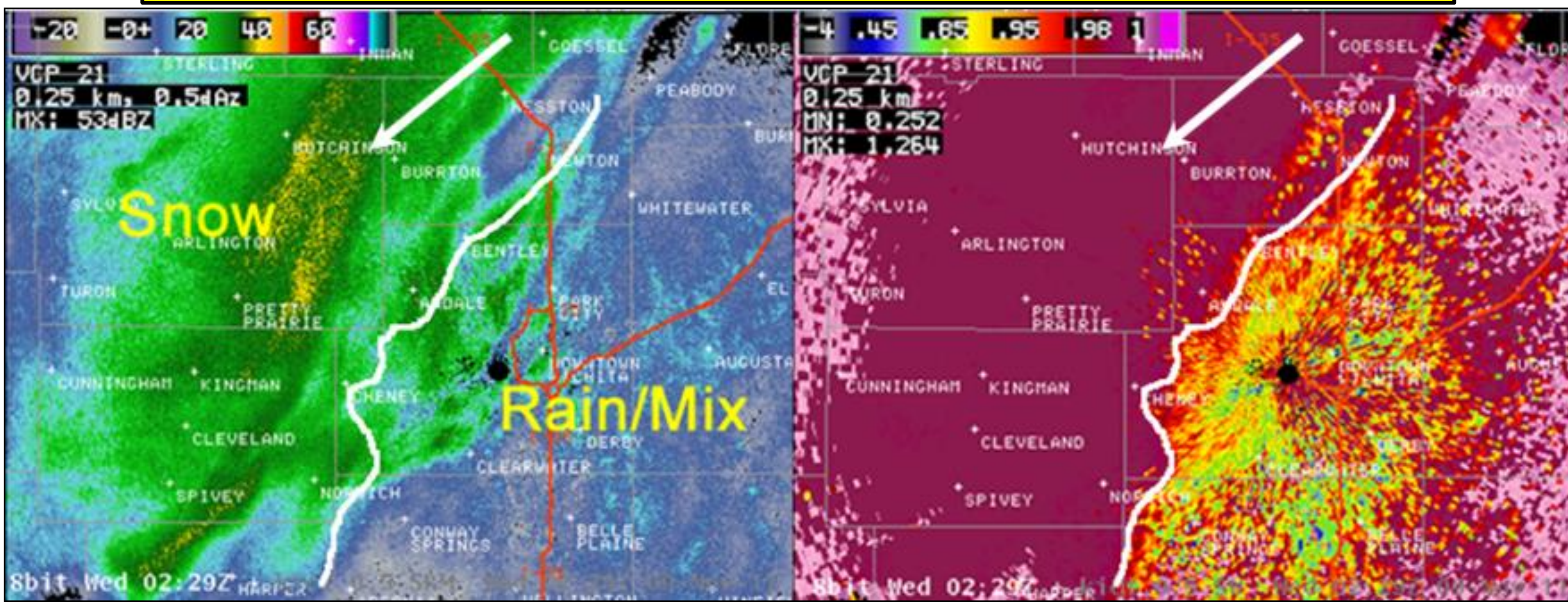
- Good for detecting the melting layer (ring of lower CC)
- Look at a higher radar elevation angles for values around 0.90 or less



CC Use/Applications: Snow vs Rain/Mixed Precipitation

Identification of Precipitation transition zones:

- In the example all snow ptype where CC > 0.97
- Rain/Icy mix where CC < 0.97



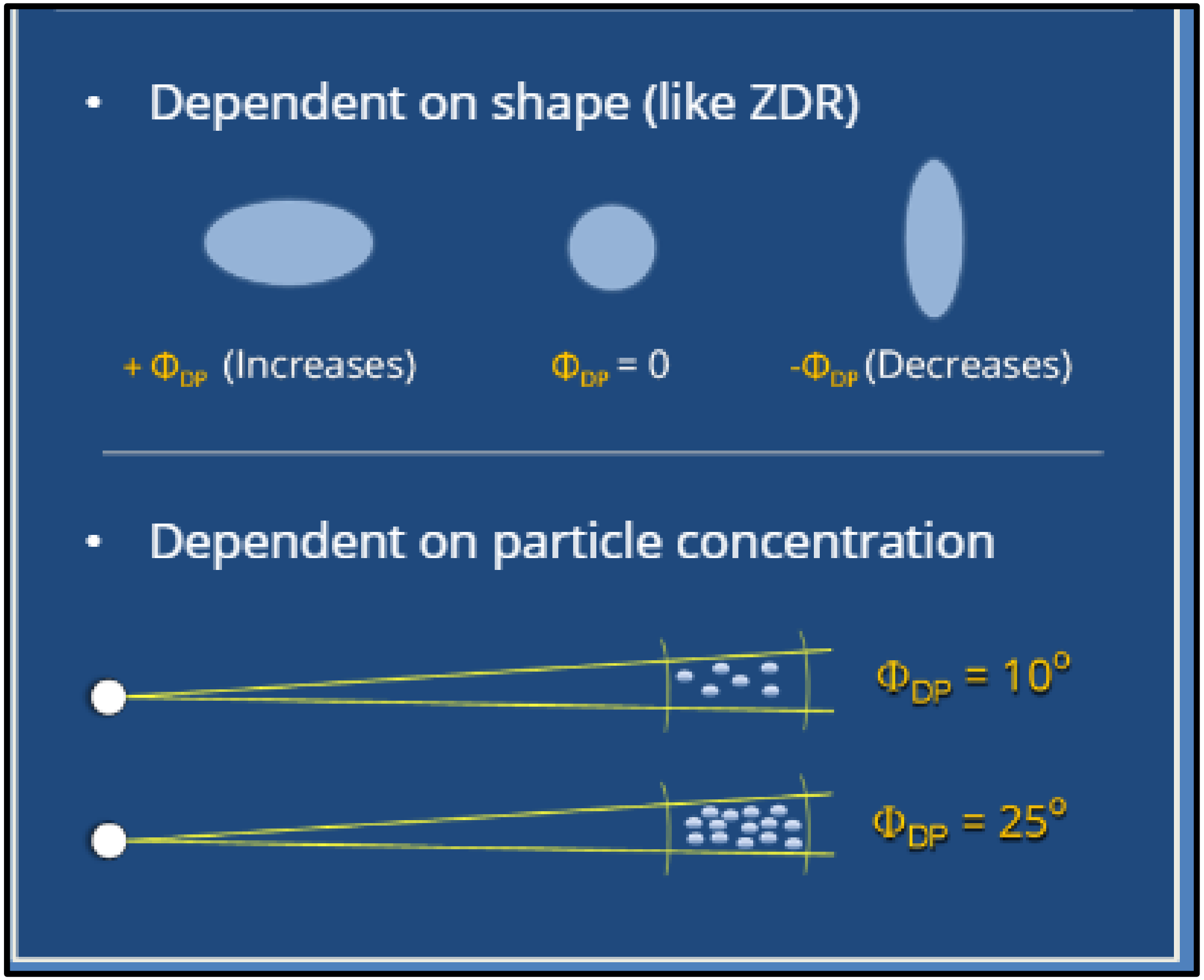
Differential Phase (Φ_{dp})

Φ_{dp}: The difference in phase shift between horizontal and vertical polarized returned energy due to forward propagation

$$\phi_{DP} = \phi_{hh} - \phi_{vv}$$

We are concerned more with Specific Differential Phase

Differential Phase (Φ_{dp}) Interpretation

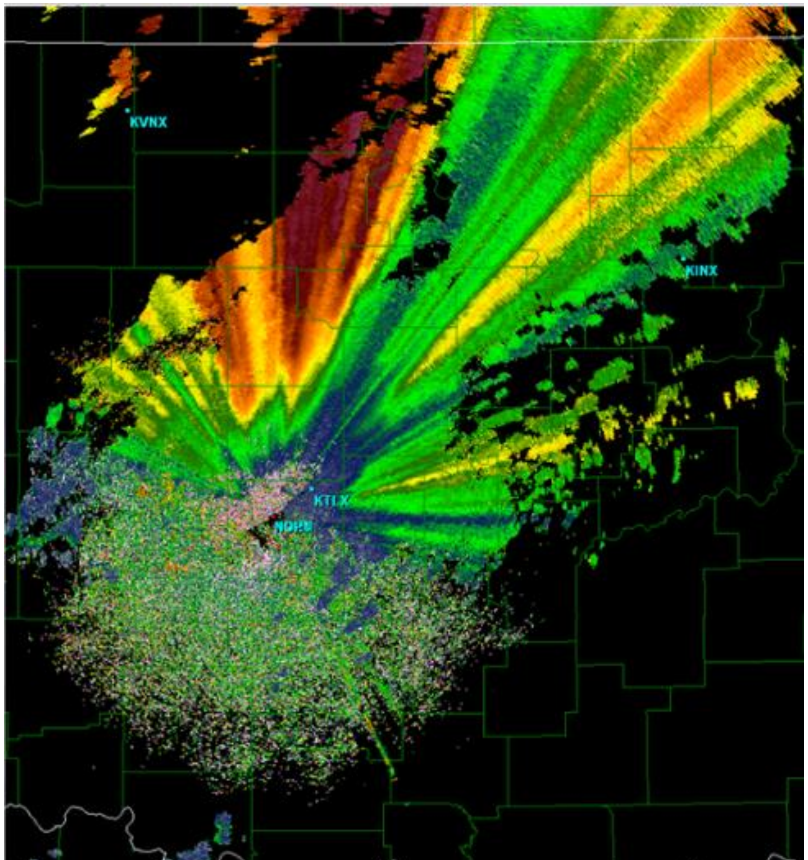


Specific Differential Phase (K_{DP})

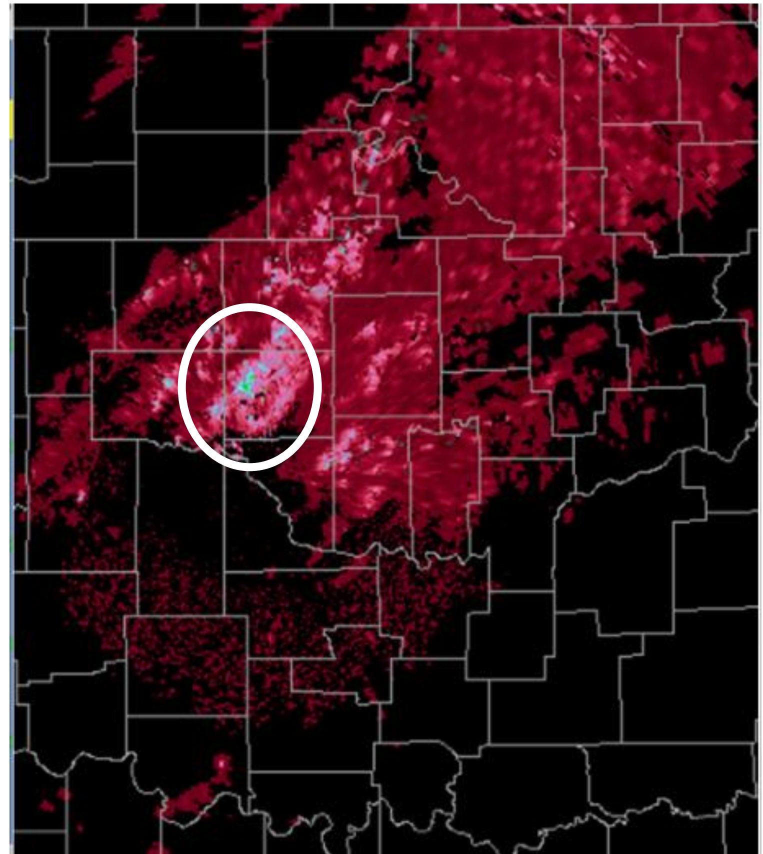
$$K_{DP} = \frac{\phi_{DP}(r_2) - \phi_{DP}(r_1)}{2(r_2 - r_1)}$$

- A derived product display what we learn from $\Phi_{DP.}$
- Since Φ_{DP} is cumulative, we use K_{DP}
  - It's basically the range derivative Φ_{DP} , but integrated along a radar radial
- Increasing values of K_{DP} imply significant amounts of liquid water regardless of ice content in a radar cross section
- Cannot be calculated for areas of very low CC (<0.90)

Φ_{dp} vs. K_{DP} (deg/km)



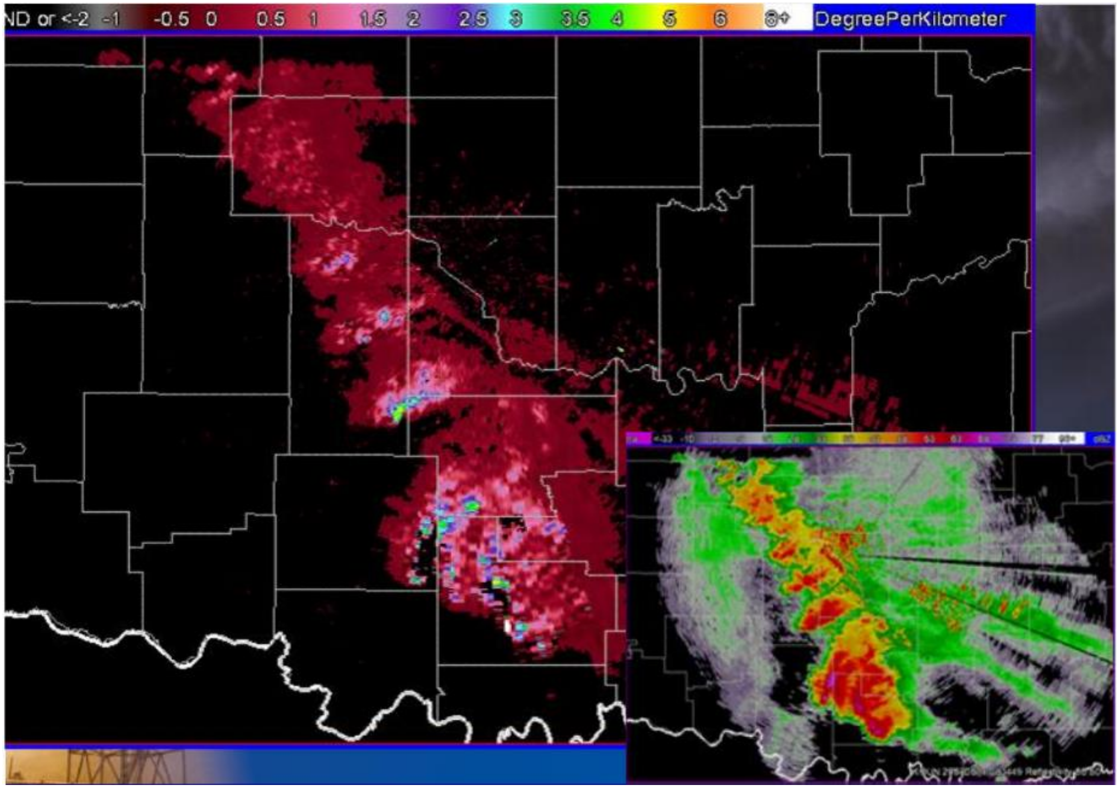
(Raw) Differential Phase (Φ_{DP})



Specific Differential Phase (KDP)

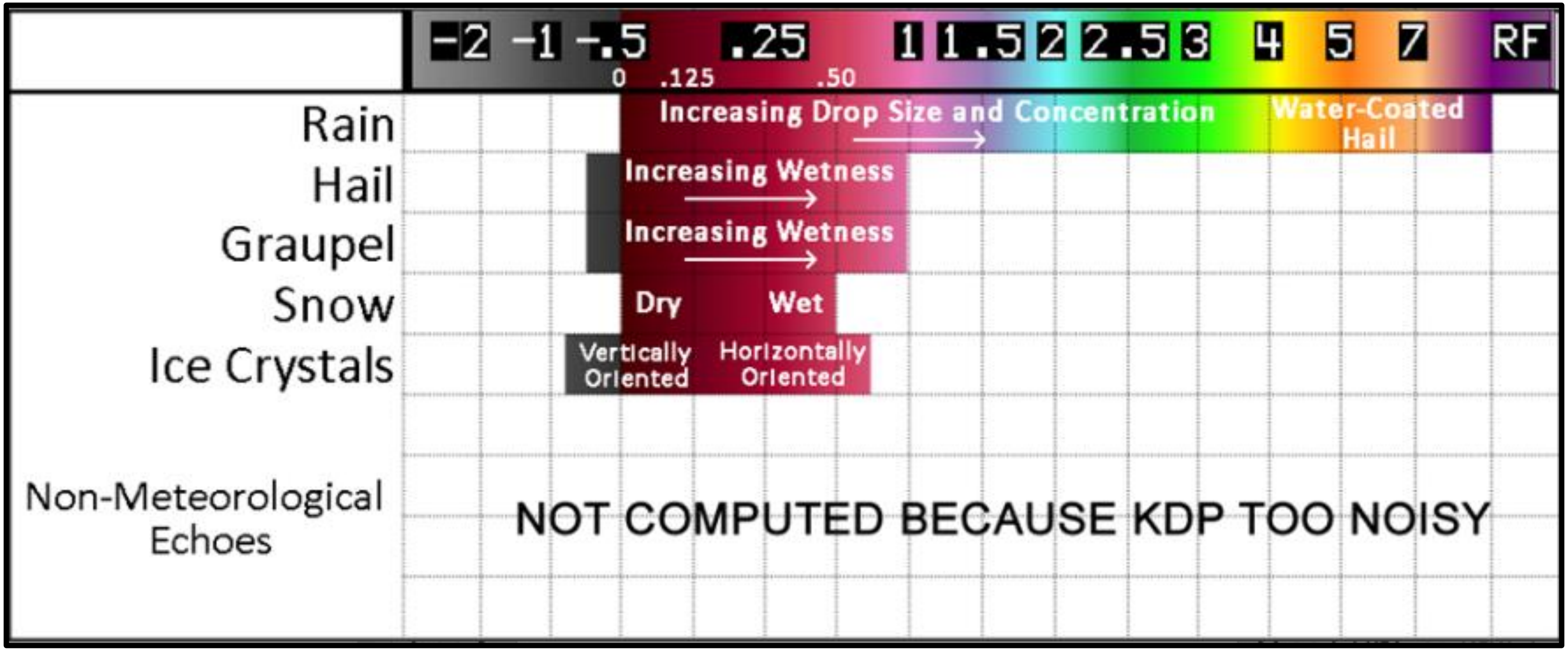
We use KDP since rain from a thunderstorm is easily able to be identified

A Radar Example of K_{DP}



The higher the values of K_{DP}, the higher the concentration of large liquid raindrops.

Values of K_{DP} (deg/km)

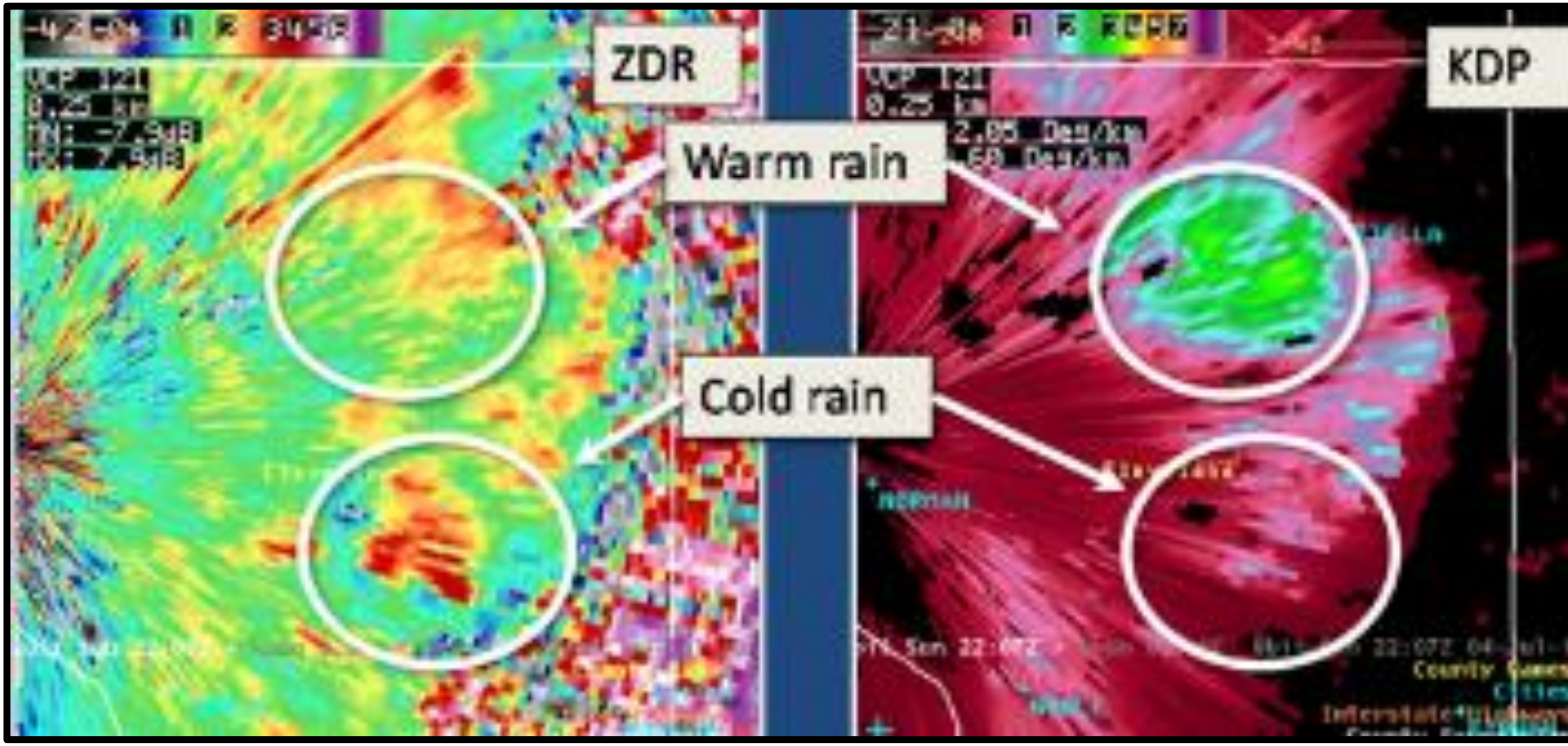


- Wide range of values for rain
- CC <0.90 ,then no KDP calculation

KDP Uses/Applications

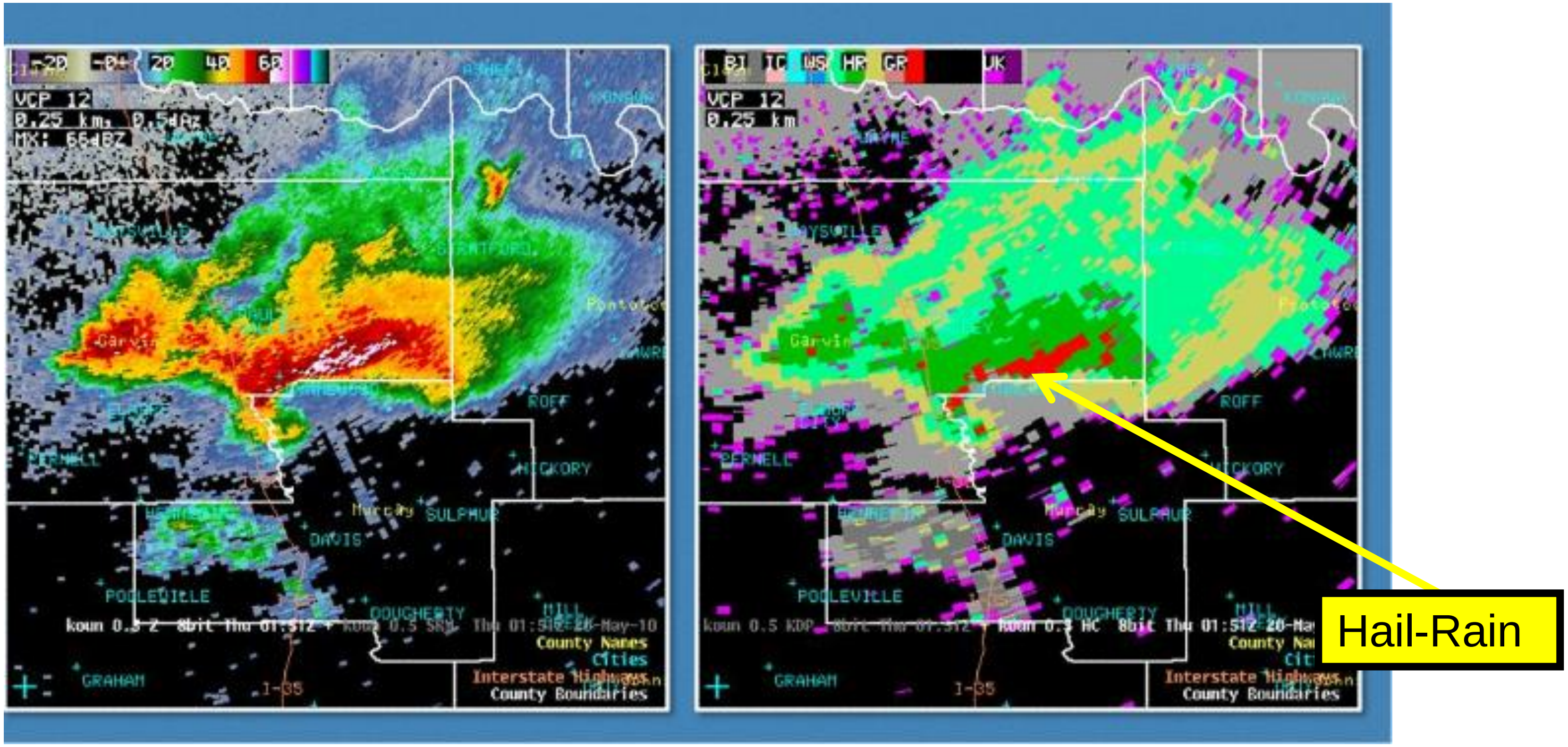
- Heavy Rain (examples shown)
- Rain/Hail Mixtures
- Small Hail Caveat (high KDP with rain, and melting hail or small hail stones)
- Warm vs Cold Rain (example next slide)

Warm vs Cold Rain Example



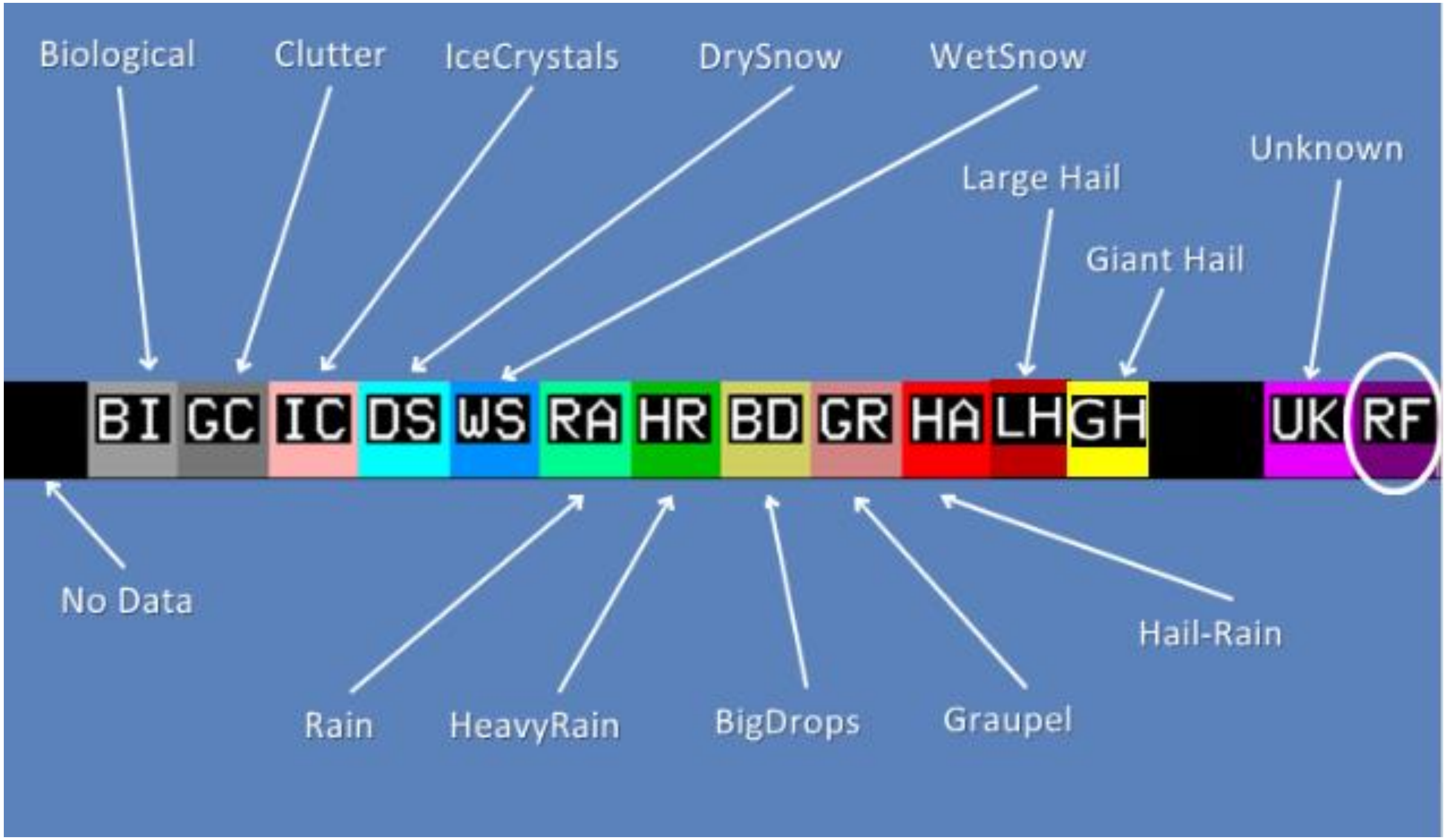
Identification of warm (efficient) rain processes vs. Cold (inefficient) processes

Hydrometeor Classification Algorithm (HCA) Example

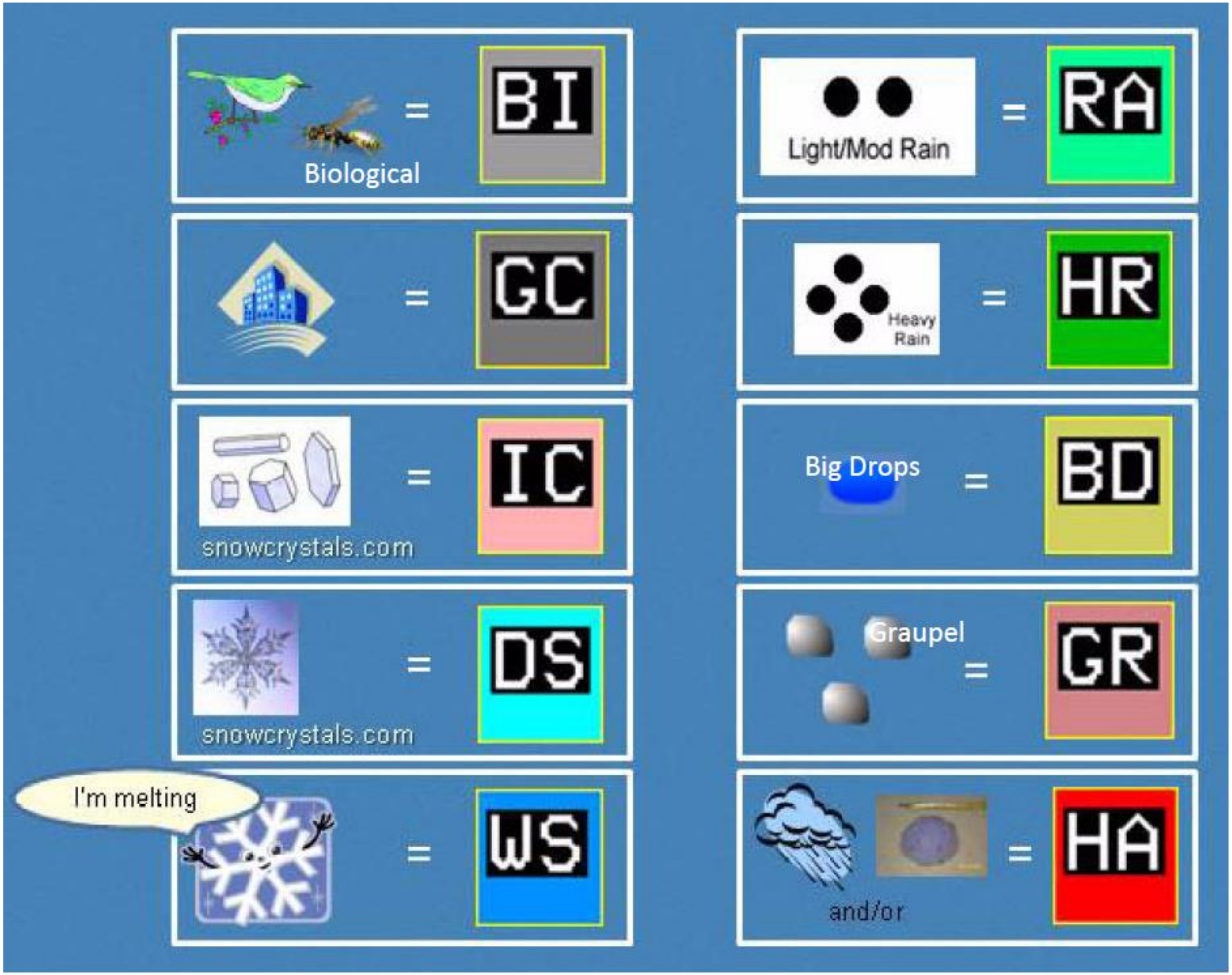


Reflectivity (Z) image on left vs. HC Algorithm output on right

Hydrometeor Classification

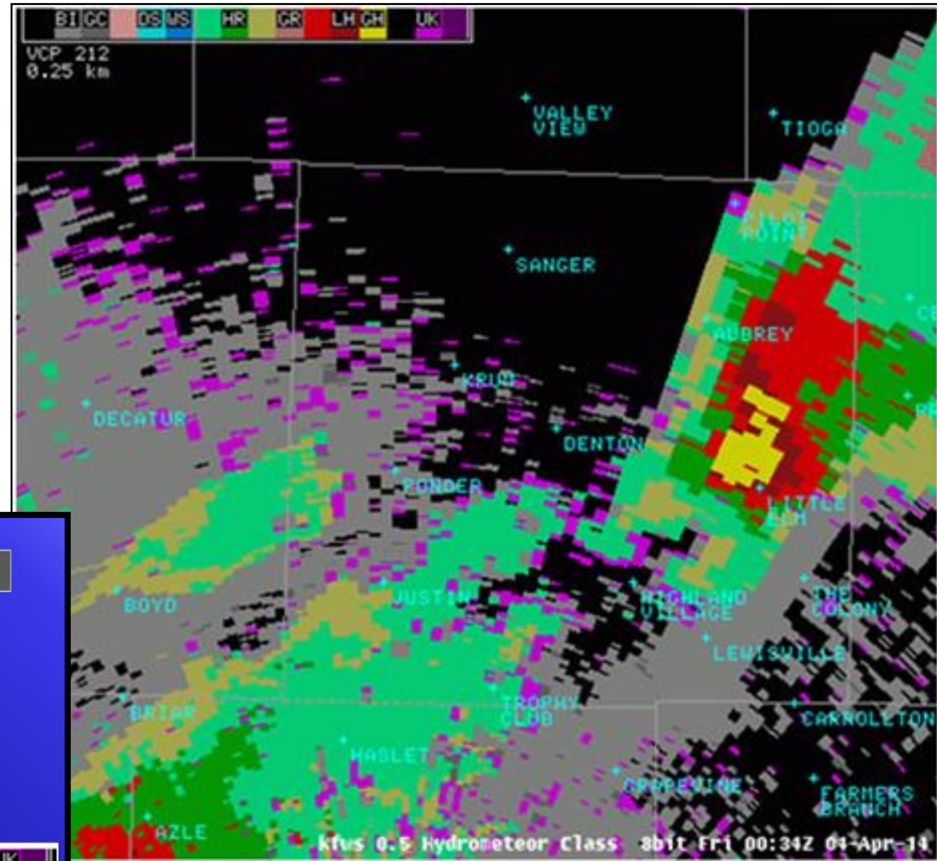


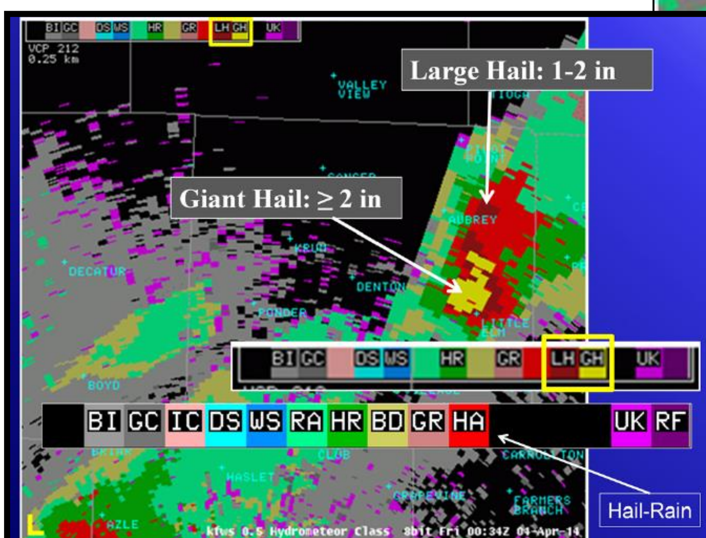
Visualization of the HC Types



Hail Size Discrimination Algorithm (HSDA)

- 2 New Hydrometeor Classifications
  - Large Hail: 1-2”
  - Giant Hail: ≥ 2”
- Displayed on the HCA Product
  - HC is a key dual pol benefit
- Requires height of the 0ºC & -25ºC Wet bulb zero height





R(KDP): Hail hydro Classes (HA, LH & GH)

From: WDTB Build 17.0 training

HCA Application/Strengths

- Safety net for base data analysis (use in conjunction with Dual Pol products)
- Key Input for precipitation algorithms
- "Quick look" for areas of concern (i.e. where the most intense storms are located in a severe weather event)
- Can help an individuals situational awareness rapidly. Remember first guess only!

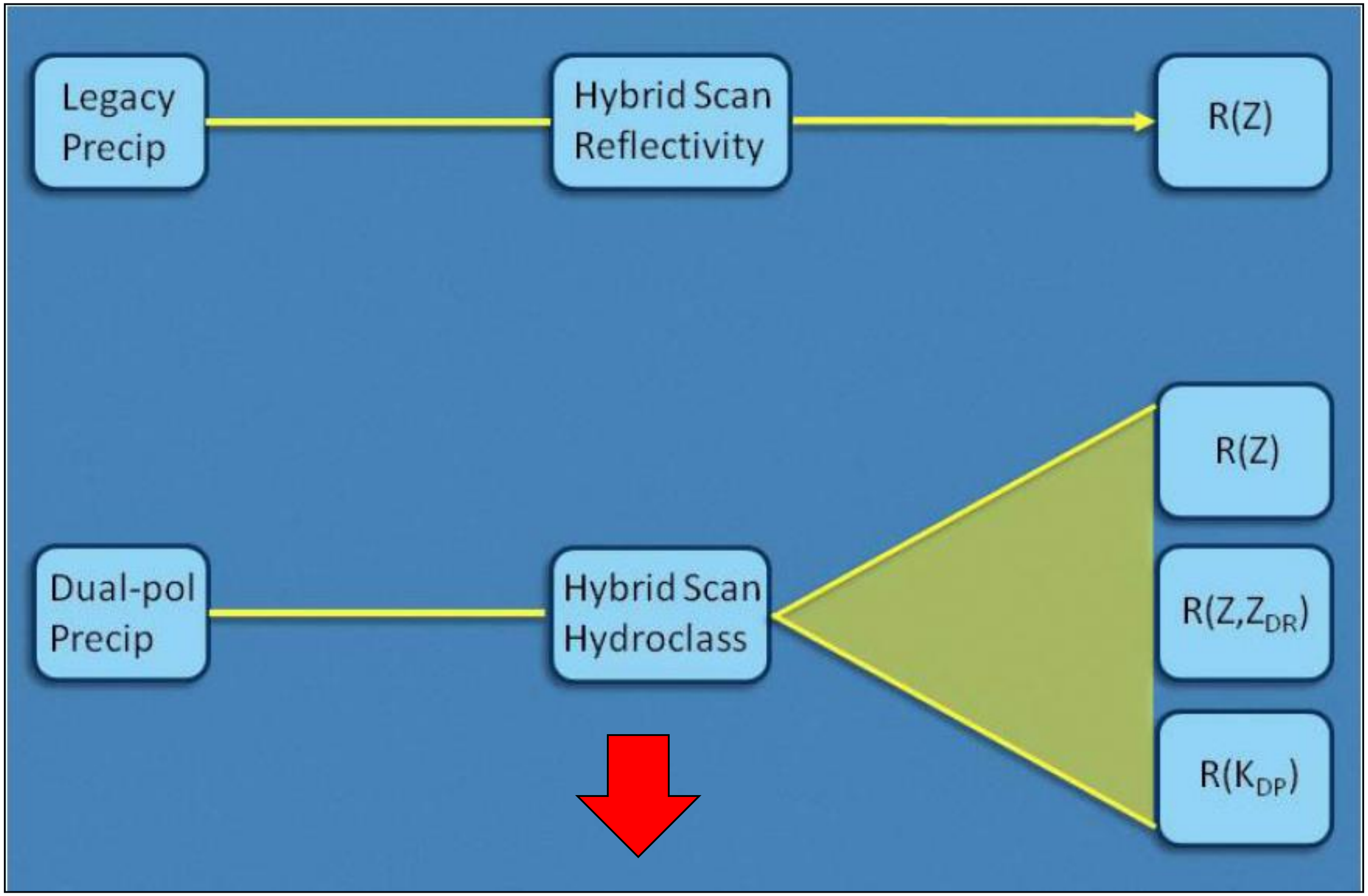
HCA Limitations/Weaknesses

- Overlapping polarimetric characteristics between classes
- Subjective and empirical fuzzy-logic membership functions and weights
- Uncertainty not given
- It is an algorithm (garbage in = garbage out)
- Ground Truth(below the beam radar effects)
- Limited ptype characteristics: no sleet, ash, etc.

Ground Truth Example: HC Weakness

Below the radar beam effects are illustrated here !!!

Dual Pol QPE "Precip" Products



The HHC product is used as input for a variety of rainfall rate relationships used for a particular location that is specific to the dominant hydrometeor type at that location, potentially improving rainfall rate compared to estimations based only on reflectivity.

9 "Newer" QPE Products

Product Type	Product Name	Abbreviation	Resolution	Data Levels
Instantaneous	1. Hybrid Hydroclass	HHC	0.25 km X 1 deg.	256 (8-bit)
	2. Digital Precipitation Rate	DPR	0.25 km X 1 deg	65536 (16-bit)
Accumulation	3. Digital Accumulation Array	DAA	0.25 km X 1 deg	256 (8-bit)
	4. One Hour Accumulation	OHA	2 km X 1 deg	16 (4-bit)
	5. Digital Storm Total Accumulation	DSA	0.25 km X 1 deg	256 (8-bit)
	6. Storm Total Accumulation	STA	2 km X 1 deg	16 (4-bit)
Difference	7. Digital One Hour Difference	DOD	0.25 km X 1 deg	256 (8-bit)
	8. Digital Storm-Total Difference	DSD	0.25 km X 1 deg	256 (8-bit)
User-selectable	9. Digital User-Selectable Accumulation	DUA 1,2,3,6,12,24	0.25 km X 1 deg	256 (8-bit)

Dual Polarization Summary

- Dual Pol data helps improve hydrometeor detection, shape, distribution and orientation
- Identification of non-meteorological targets more easily
- Improvement on the detection of hail in a thunderstorm (Large Hail, Hail vs. Rain, etc.)
- Differentiate between rain, snow, and mixed pcpn
- Detection of areas of heavy rain/flooding better
- Tornado Debris Signature (TDS) identification
- Identification of the melting layer/bright band