Severe Weather Warning Techniques

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Severe Hail

Severe Hail Indicators

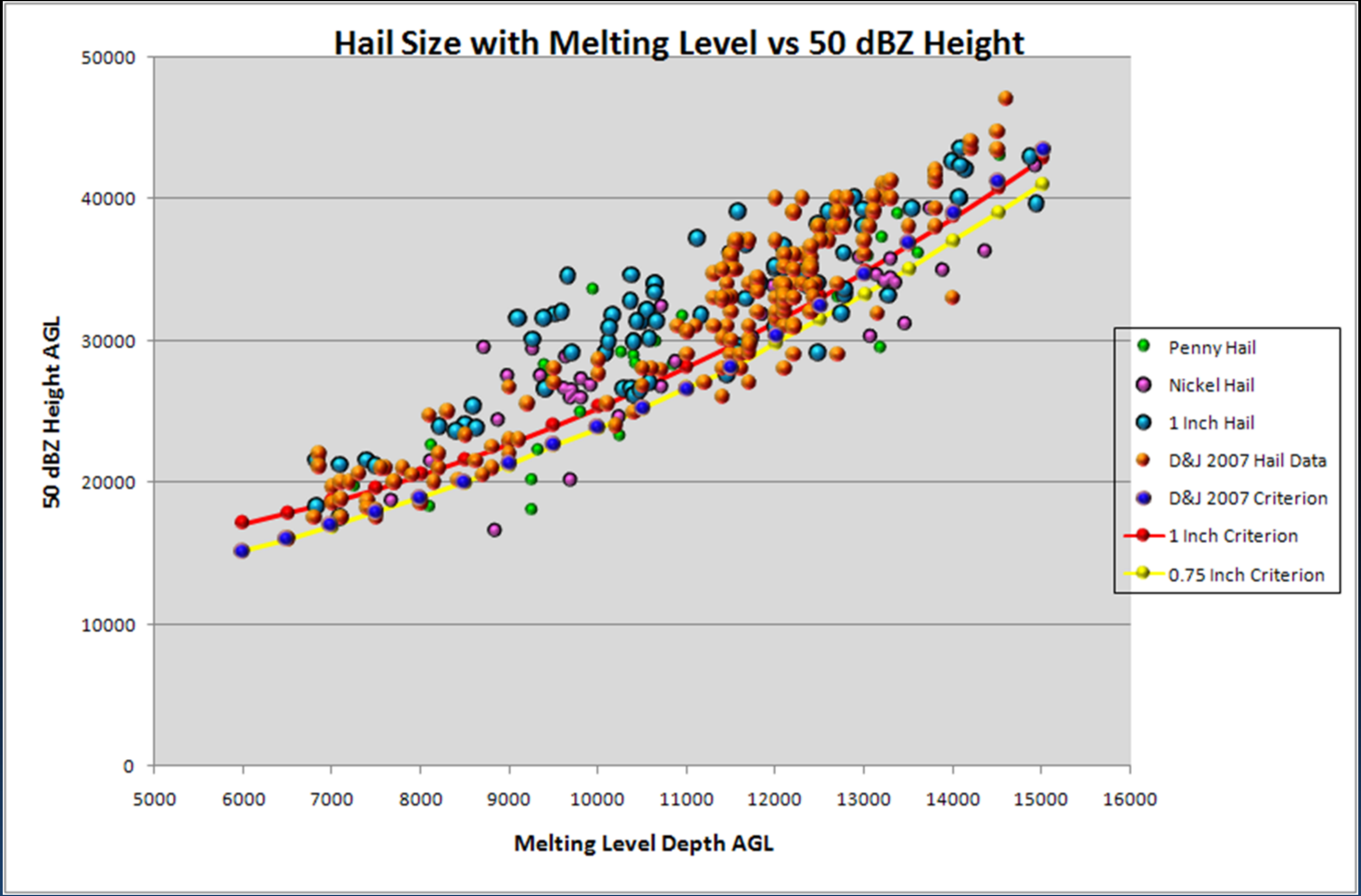
- Donavon Technique
- MRMS Products:
  - MESH
  - Reflectivity at -20 °C (60 dBZ)
- TBSS
- Dual-Pol Products
- Storm-Top Divergence
- WER/BWER
- Lemon Technique

Donavon Technique

- A proxy for updraft strength and 1”+ hail development.
- Relationship between the Melting Level (ML) and the height of the 50 dBZ echo.
- The Higher the ML, the Higher the 50 dBZ echo height needs to be.

Donavon 2010 (Updated for 1” hail)

Previous research in 2007 focused on ¾” hail



Donavon (2010) Hail Criteria

•MDepth(AGL)	0.75” in Criterion	1 in Criterion	1.75 in Criterion
•6000 ft	15176 ft	17116 ft	19800 ft
•6500 ft	16000 ft	17850 ft	20907 ft
•7000 ft	16903 ft	18666 ft	22272 ft
•7500 ft	17900 ft	19563 ft	23663 ft
•8000 ft	18916 ft	20542 ft	25077 ft
•8500 ft	19980 ft	21602 ft	26516 ft
•9000 ft	21214 ft	22745 ft	27979 ft
•9500 ft	22580 ft	23969 ft	29465 ft
•10000 ft	23798 ft	25274 ft	30976 ft
•10500 ft	25180 ft	26661 ft	32511 ft
•11000 ft	26667 ft	28130 ft	34070 ft
•11500 ft	28020 ft	29680 ft	35654 ft
•12000 ft	29821 ft	31312 ft	37261 ft
•12500 ft	31500 ft	33025 ft	38893 ft
•13000 ft	33261 ft	34820 ft	40549 ft
•13500 ft	35000 ft	36697 ft	42229 ft
•14000 ft	36987 ft	38665 ft	43933 ft
•14500 ft	39000 ft	40695 ft	45661 ft
•15000 ft	40998 ft	42819 ft	47413 ft

Cavanaugh & Schultz (2012) Hail Criteria

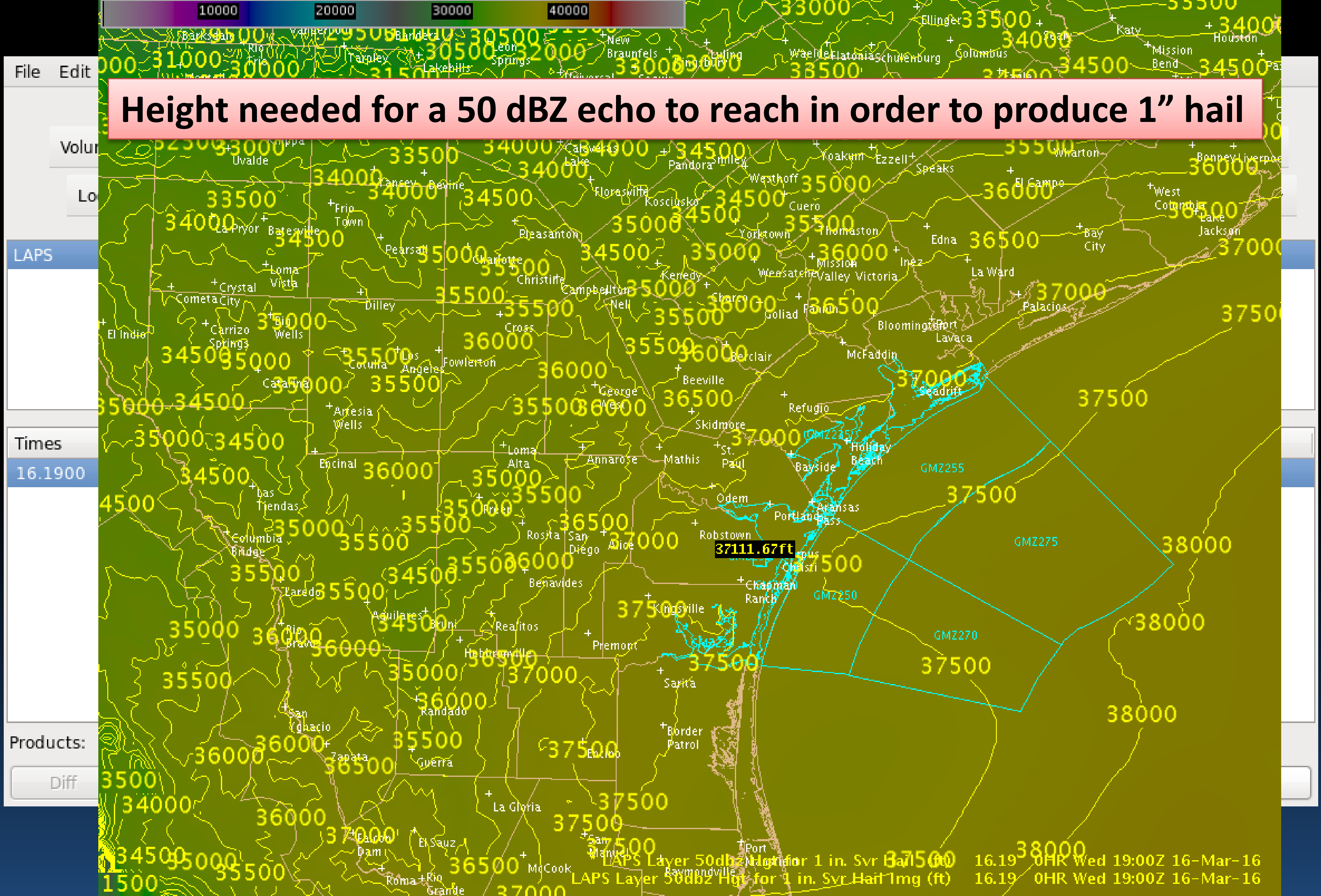
- Heights generally higher than the Donavon study.

		50 dBZ height	
Melting Level		25th Percentile	10th Percentile
6500	17850	22000	21600
7000	18666	23000	22300
7500	19563	24000	23000
8000	20542	24900	23700
8500	21602	25900	24400
9000	22745	26900	25100
9500	23969	27900	25800
10000	25274	28800	26600
10500	26661	29800	27300
11000	28130	31900	29800
11[illegible]	29680	32900	30600
[illegible]00	31312	33900	31500
12500	33025	34900	32400
13000	34820	35800	33300
13500	36697	36800	34200
14000	38665	37800	35000
14500	40695	38800	35900

Max dBZ at -20°C	Max dBZ at -20°C	Max dBZ at -20°C
Mean dBZ: 63	25th Percentile: 60	10th Percentile: 56

Donavon values

Height needed for a 50 dBZ echo to reach in order to produce 1" hail



One step further…

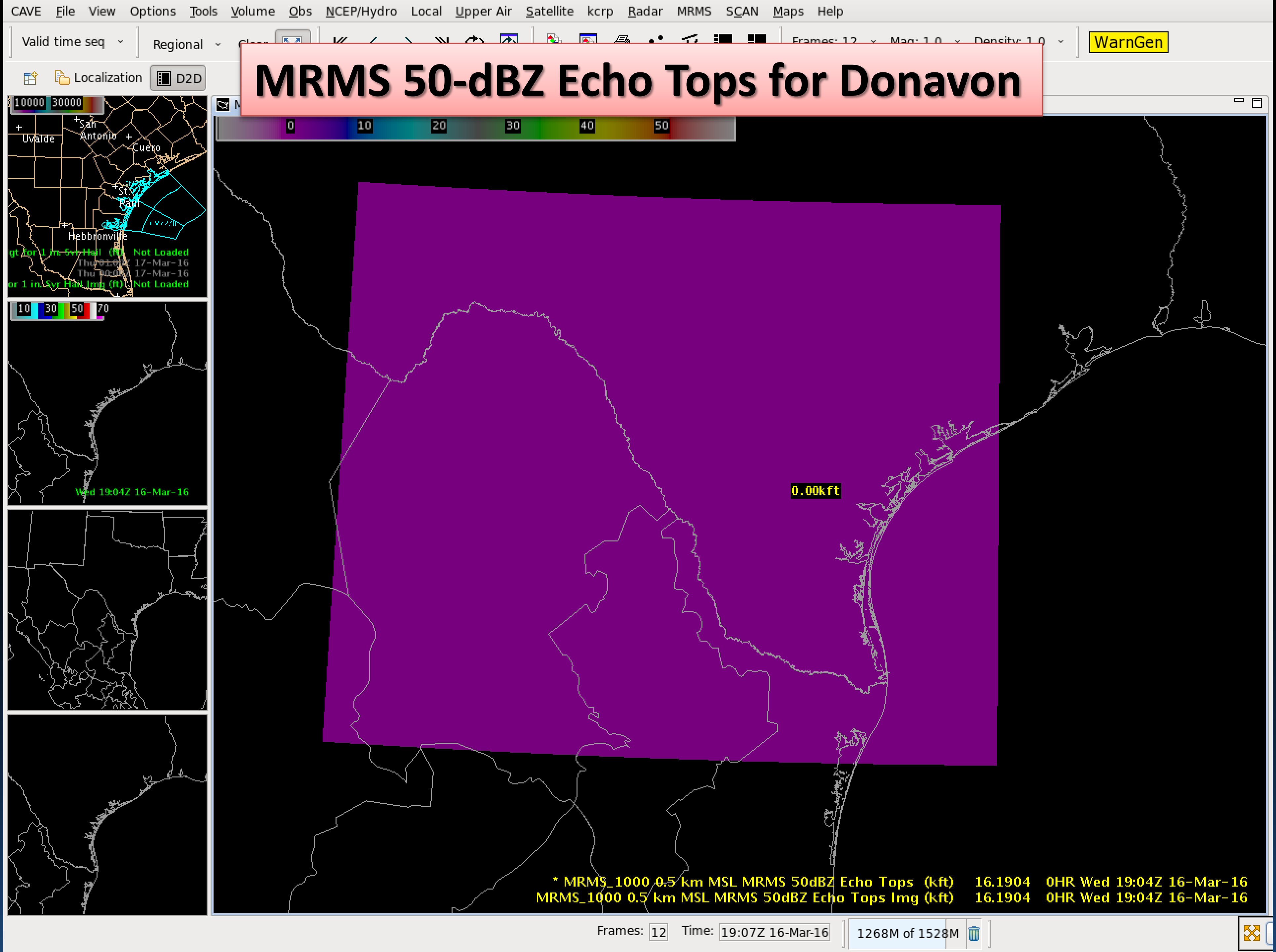
- Calculate the difference between the actual 50 dBZ echo height and the 50 dBZ echo height needed to produce 1” hail.
- Use MRMS 50 dBZ echo height for the actual height.
- MRMS 50 dBZ echo height – Donavon 50 dBZ echo height =
  - **Positive values indicate 1”+ hail likely.**
  - **Negative values indicate the Donavon criteria not met.**

2 AWIPS Fields Required to Perform this Subtraction

- **MRMS 50-dBZ Echo Tops for Donavon**
  - Baseline is 0.00 kft.
  - Original MRMS 50 dBZ echo height Baseline is “No Data”.

- **50 dBZ Hgt for 1 in. Svr Hail for MRMS**
  - Units are in kft.
  - Original 50 dBZ Hgt for 1 in. Svr Hail is in feet.

MRMS 50-dBZ Echo Tops for Donavon

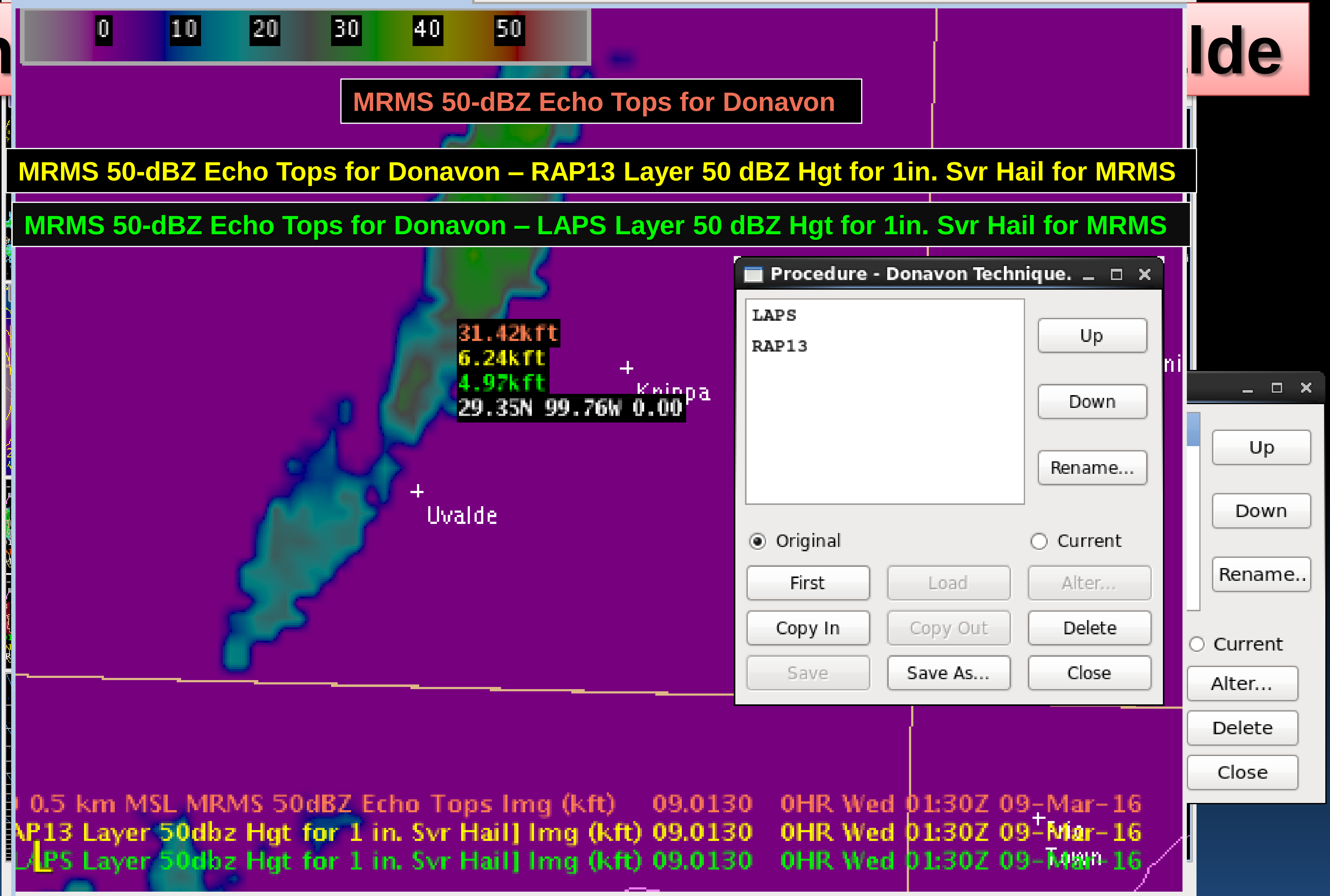


1 in ... lde

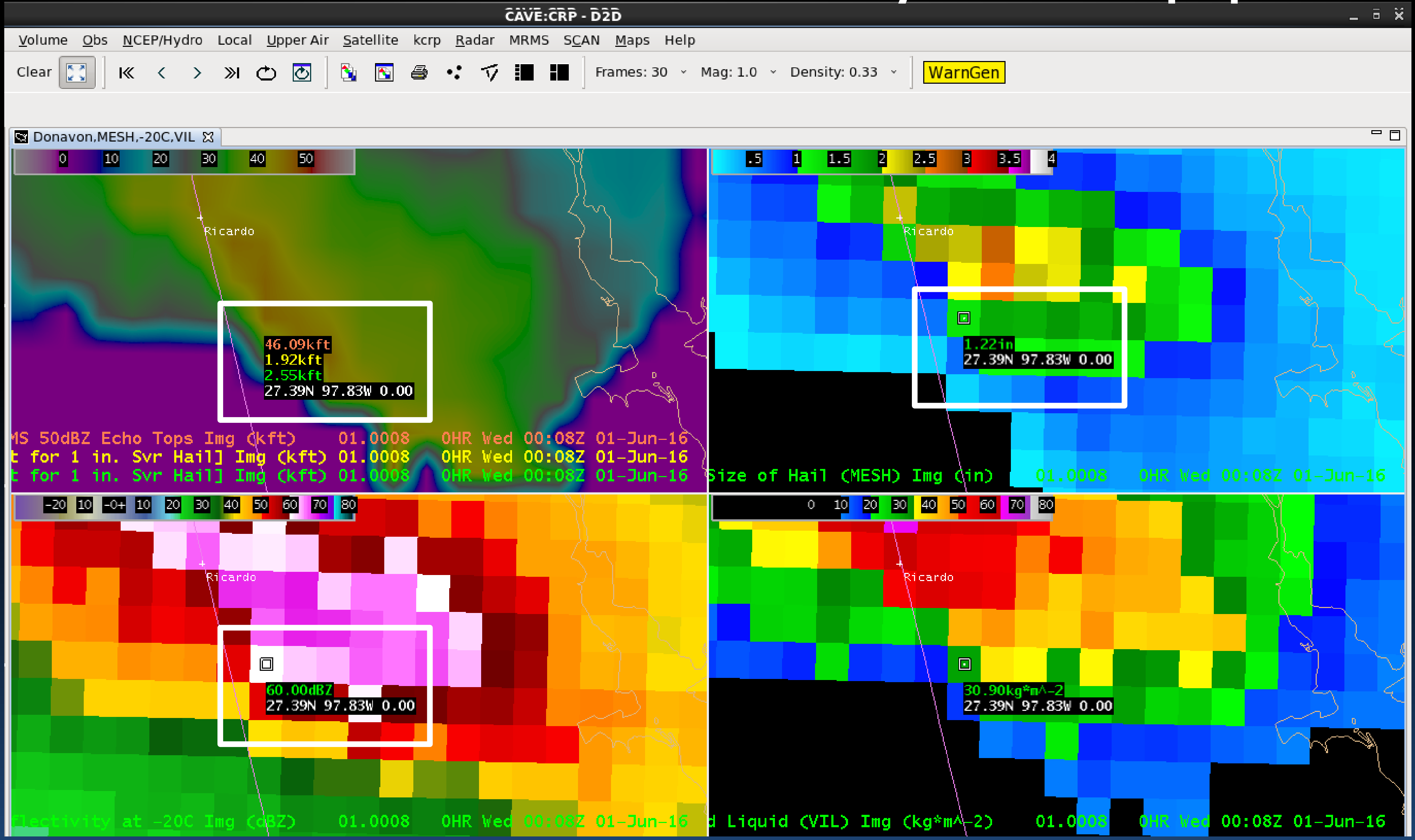
MRMS 50-dBZ Echo Tops for Donavon

MRMS 50-dBZ Echo Tops for Donavon – RAP13 Layer 50 dBZ Hgt for 1in. Svr Hail for MRMS

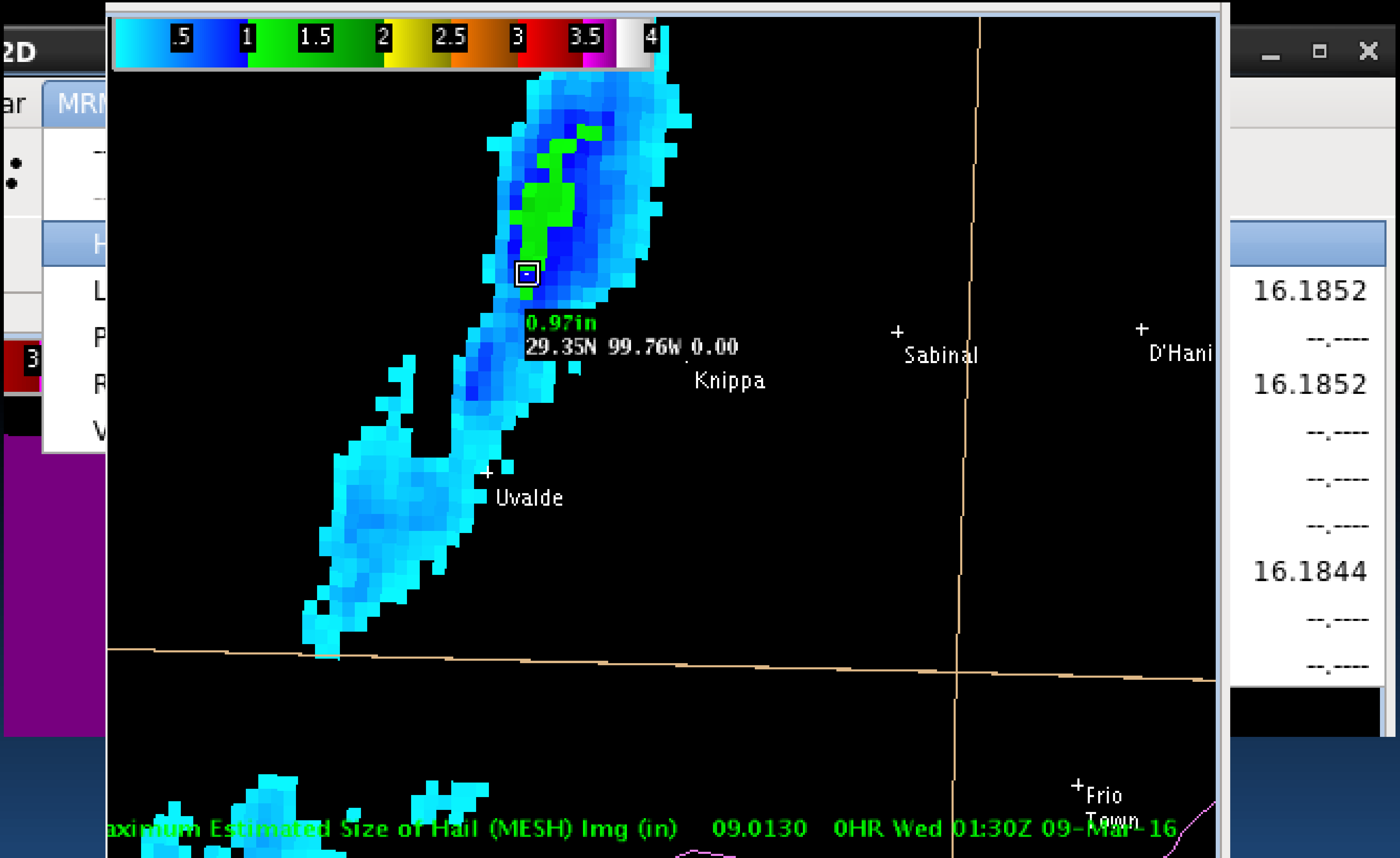
MRMS 50-dBZ Echo Tops for Donavon – LAPS Layer 50 dBZ Hgt for 1in. Svr Hail for MRMS



May 31, 2016 Baseball Size Hail in Ricardo: Hail Parameters will not always line up perfectly.



Maximum Estimated Size of Hail (MESH)

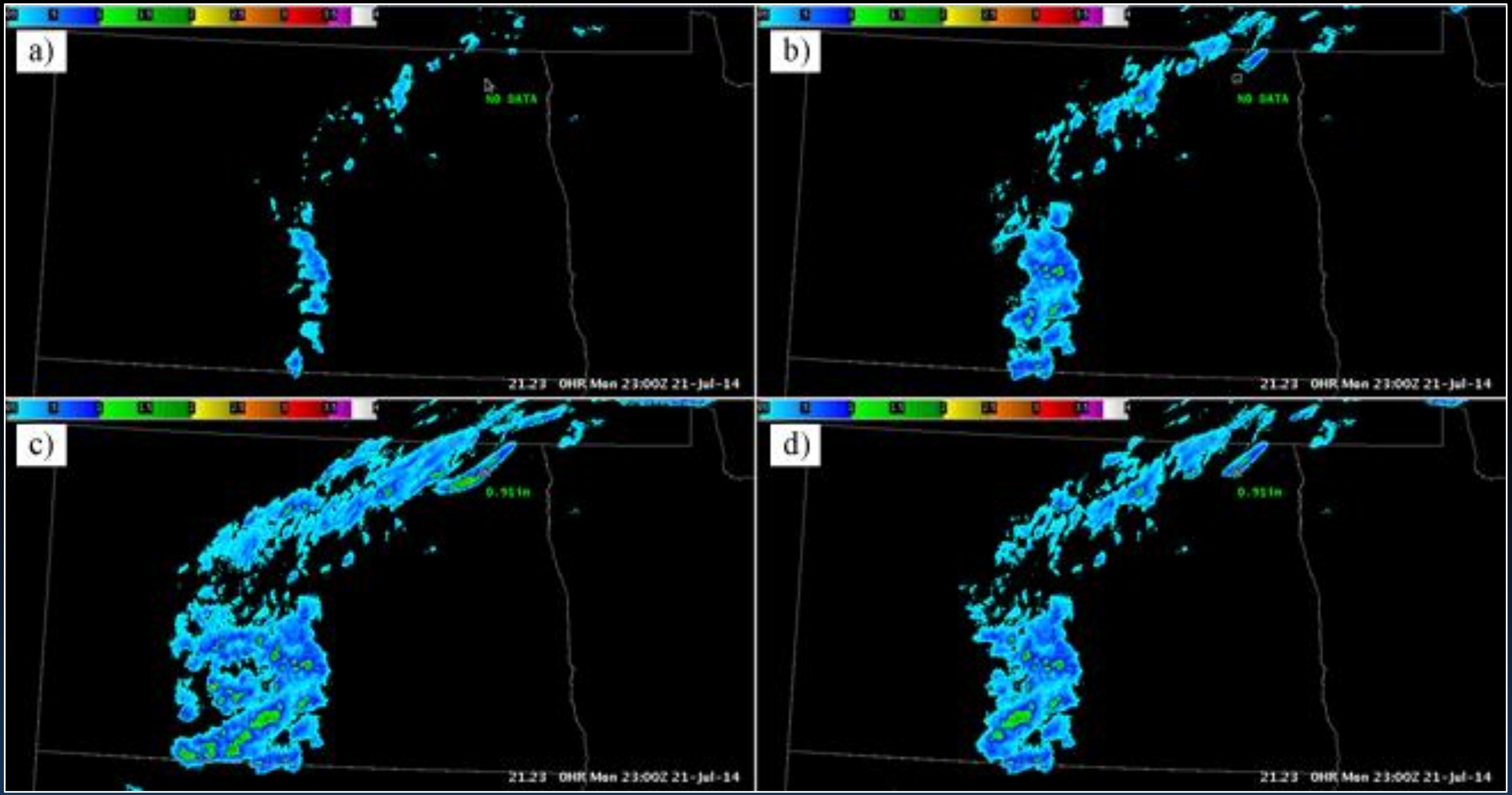


MESH

- Largest hailstone possible.
- Underestimate with:
  - Highly-tilted storms
  - Left-moving Supercells
  - Large BWER (shows up as a MESH hole)
  - Low density, dry hailstones

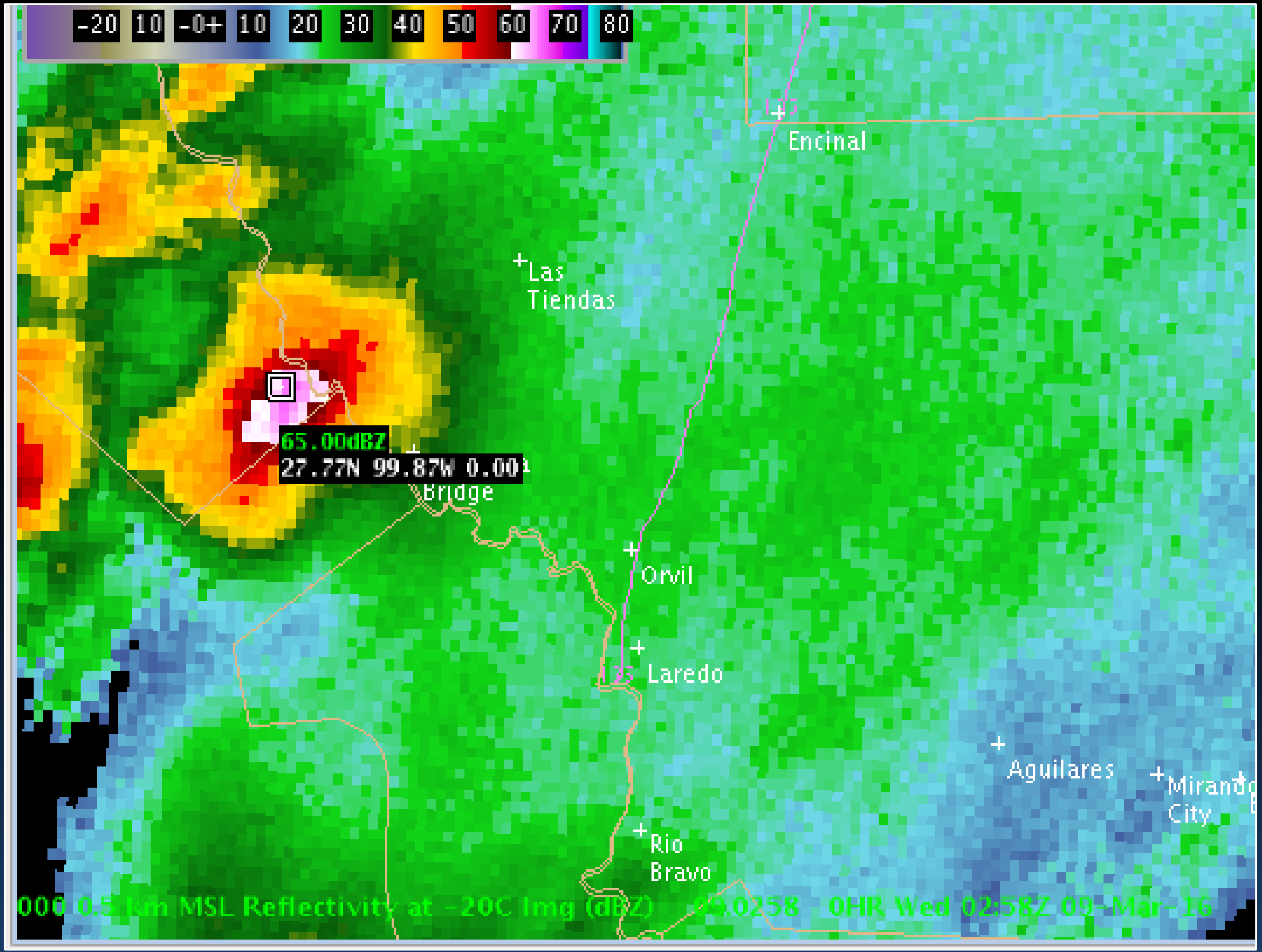
MESH Tracks

- Assess storm intensity trends.
- Assess storm motion.
  - Deviant motion



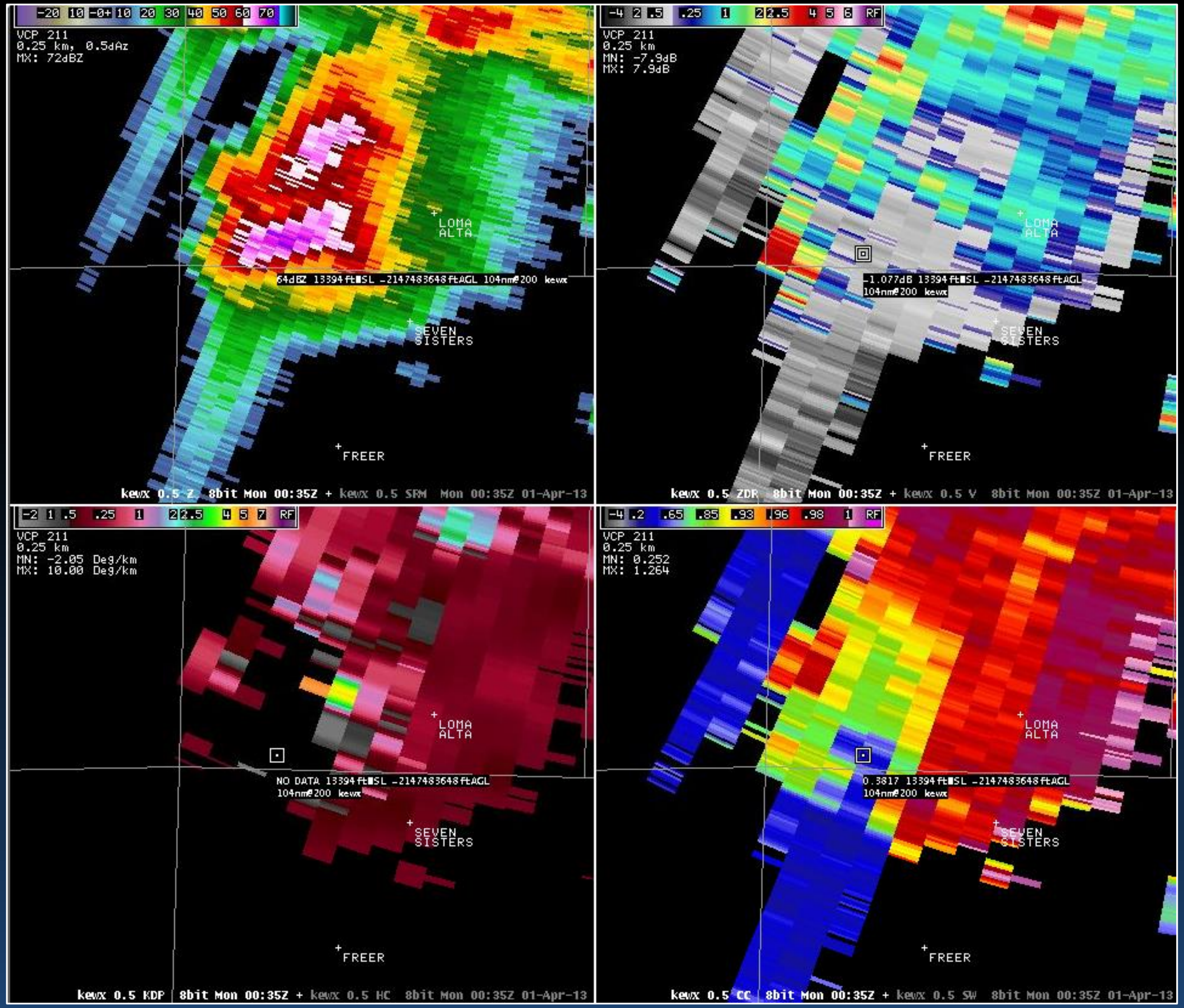
60 dBZ Reflectivity at the -20 °C level

- Favored Hail Growth Zone (-10°C to -30°C).
- Great indicator of 1”+ hail.
  - Usually Golfball or larger.
- Z ≥ 60 dBZ at any level or 50 dBZ at -20°C suggests hail of any size.



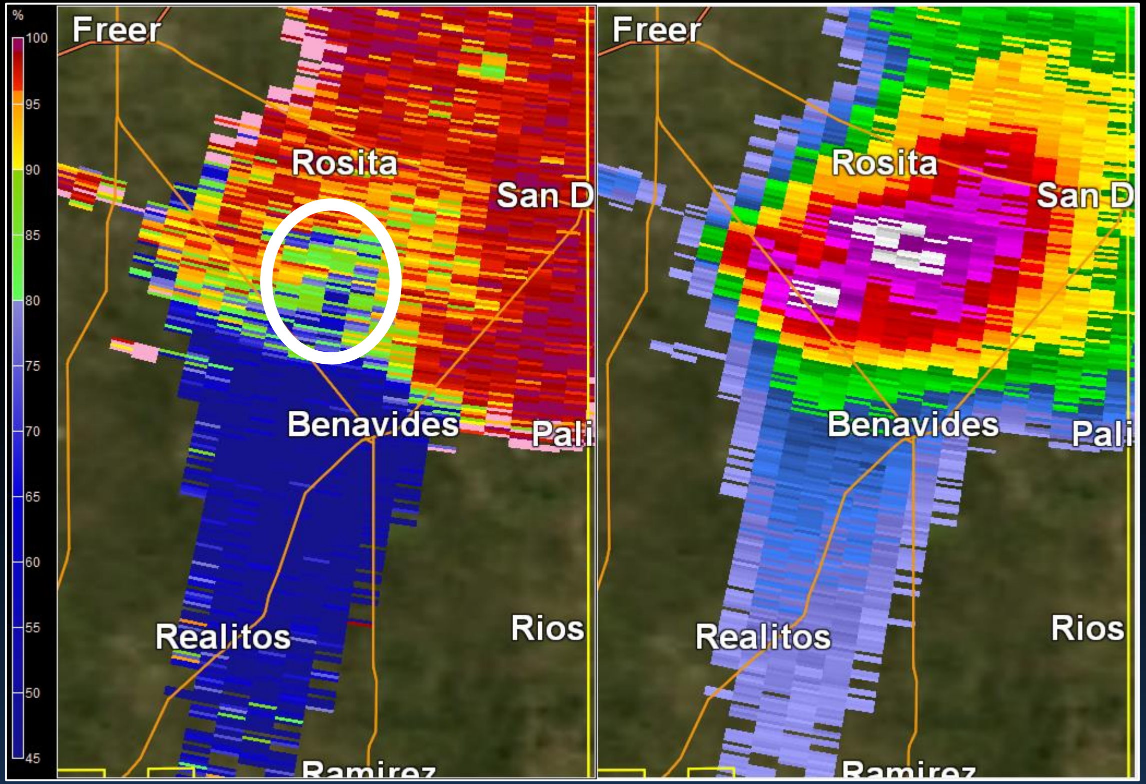
Three-Body Scatter Spike (TBSS)

- Mie Scattering produces TBSS.
- Z < 25 dBZ; CC < 0.5; ZDR extreme positive transitioning to lower positive or negative.
- Presence of Severe Hail is likely.
- If Z ≥ 5 dBZ, then Golfball size or larger hail is present.
  - "Pronounced TBSS"

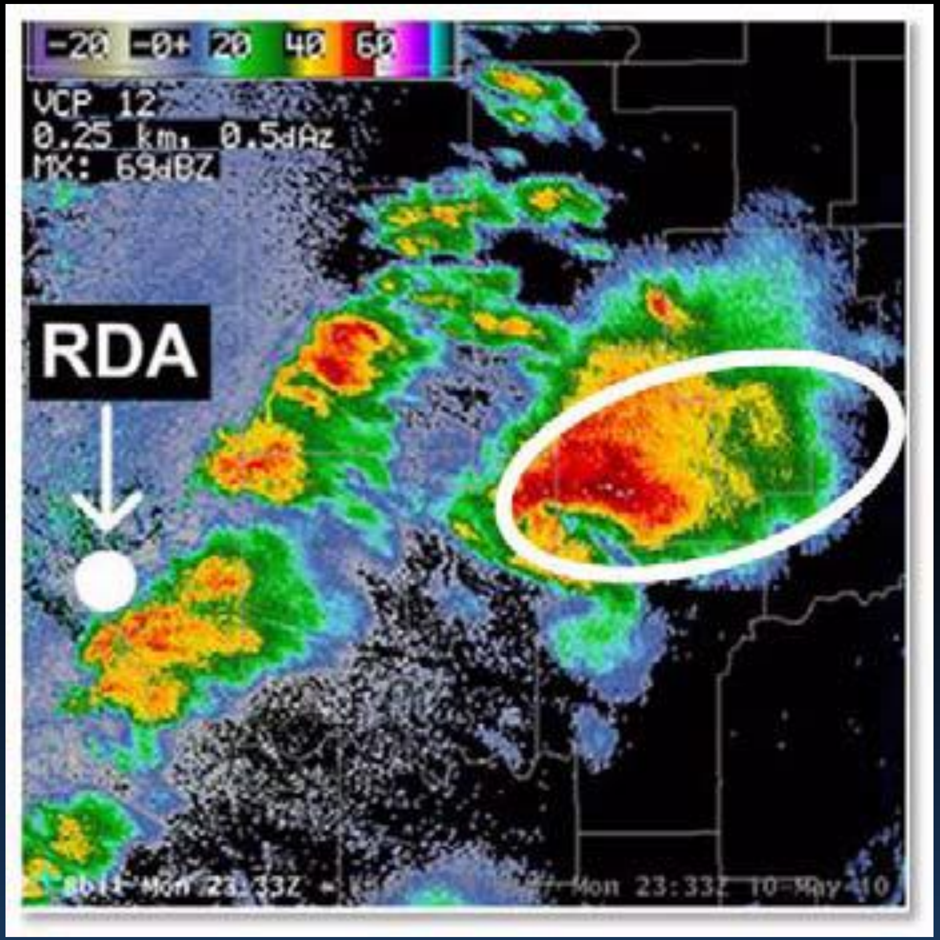


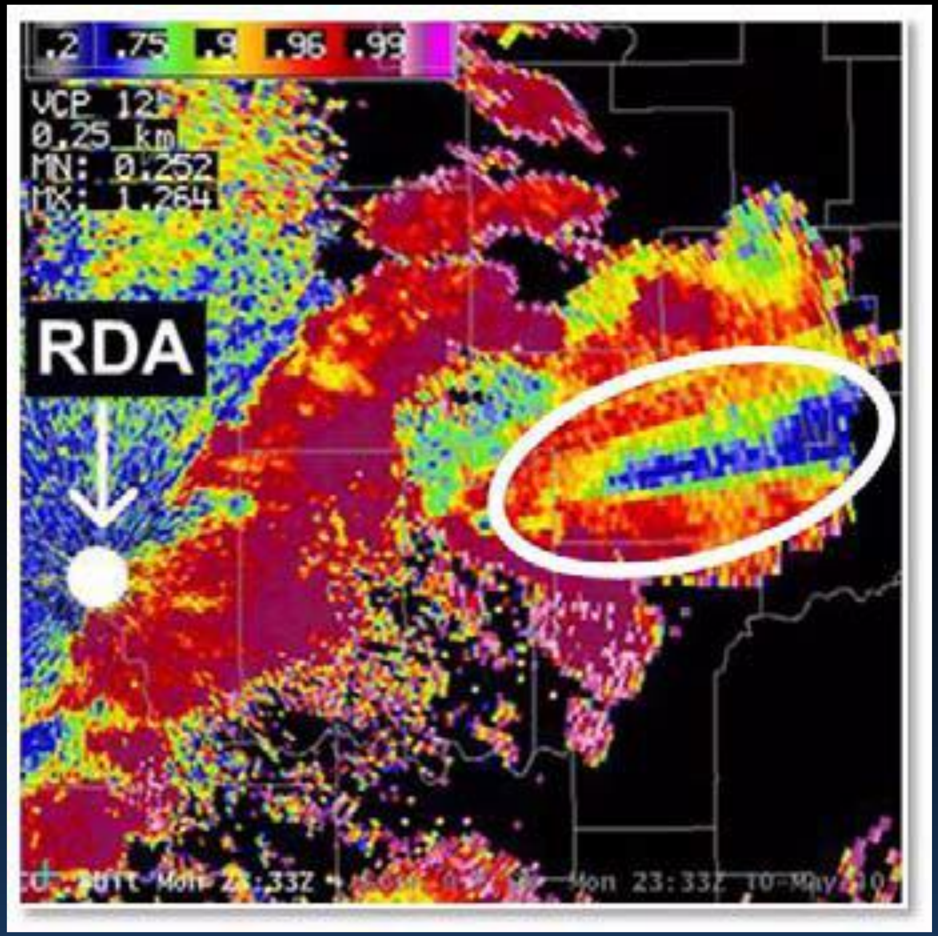
Correlation Coefficient (CC)

- A measure of uniformity among horizontal and vertical pulses.
- Most consistent indicator of hail near the surface.
- 0.70 ≥ CC ≤ 0.97 for hail.
  - CC < 0.85-0.90 equates to larger than golfball size.



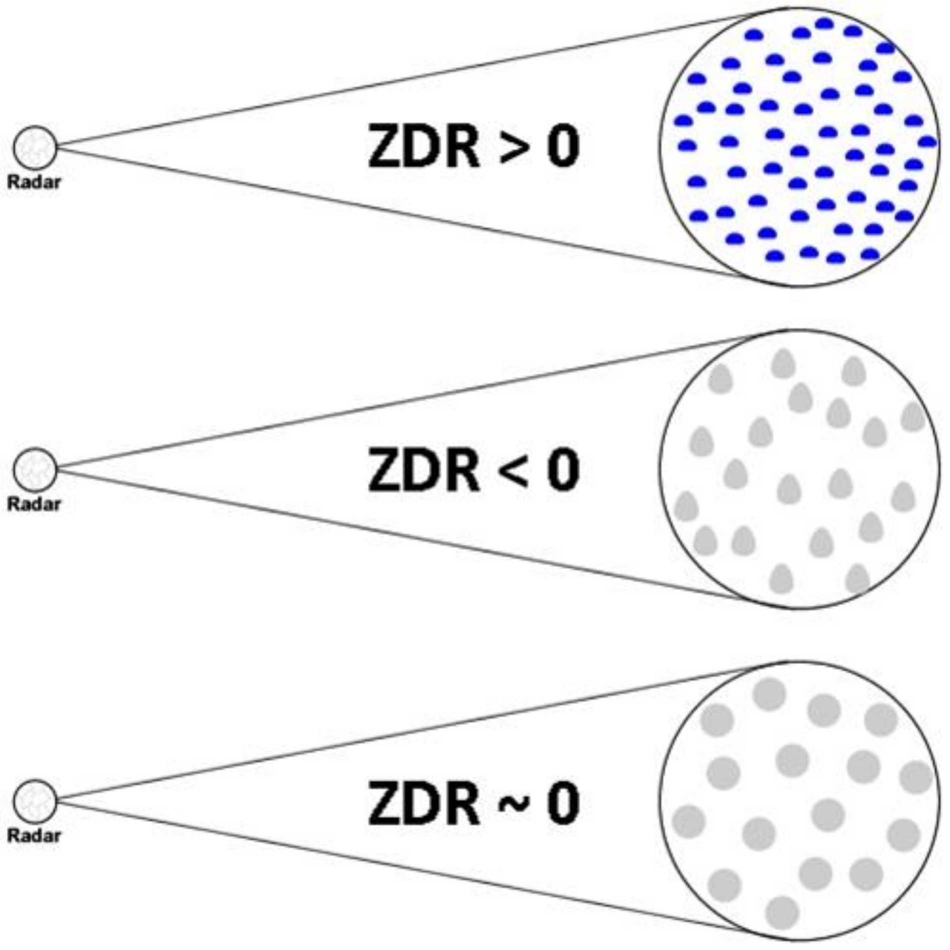
Beware of Non-Uniform Beam Filling!





Differential Reflectivity (ZDR)

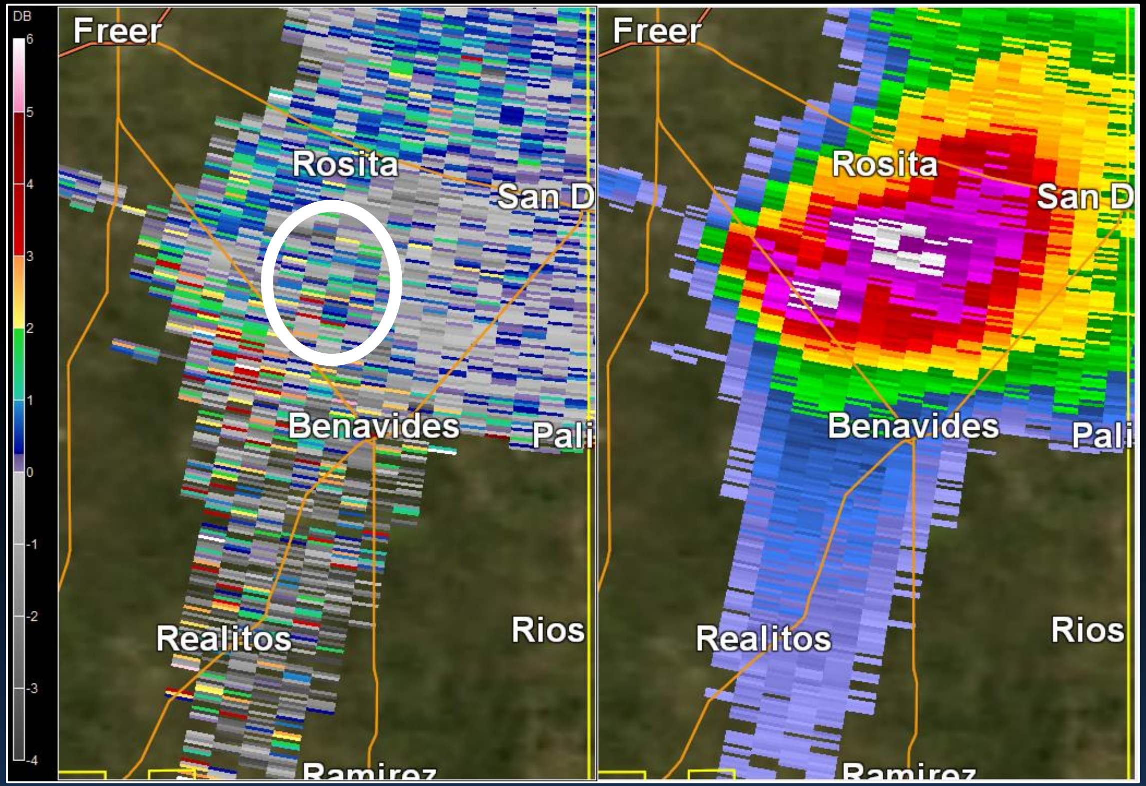
- Difference between horizontal and vertical reflectivity factors (**$ZDR = Z_H - Z_V$**).



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

Differential Reflectivity (ZDR)

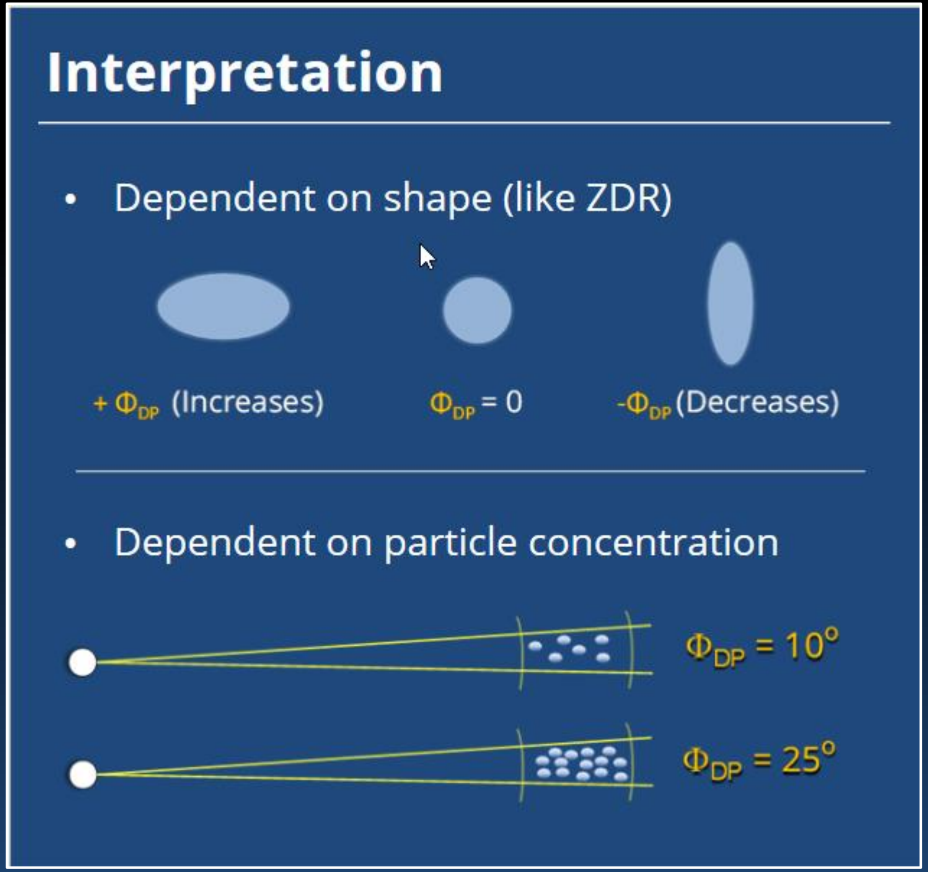
- ZDR -0.5 to 1.5 dB due to tumbling motion of hail.
- ZDR ~ 0 dB along with high Z means hail is occurring.
- ZDR ≤ 0 dB along with high Z and CC < 0.85-0.9 means > 2” hail.



Specific Differential Phase (KDP)

- Change in Differential Phase Shift (Φ_{DP}).
  - Φ_{DP} is the difference between horizontal and vertical 2-way propagation phase shifts.

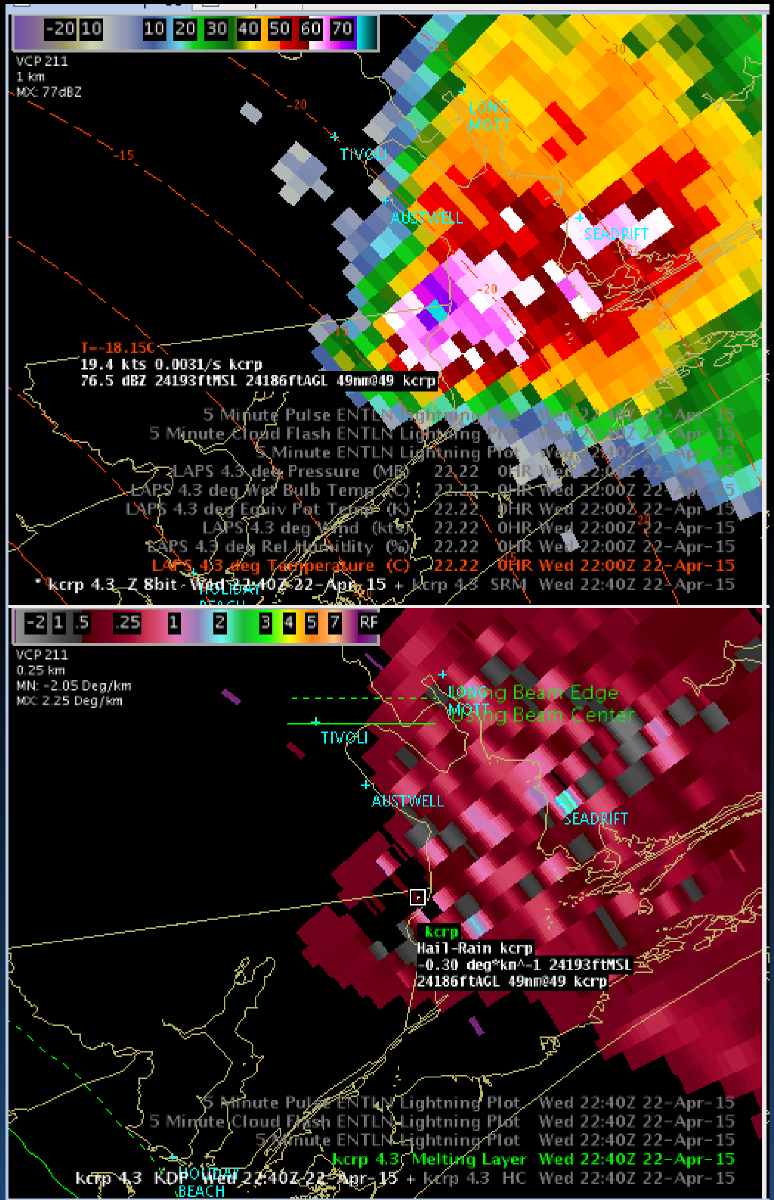
$$\Phi_{DP} = \Phi_H - \Phi_V$$



Specific Differential Phase (KDP)

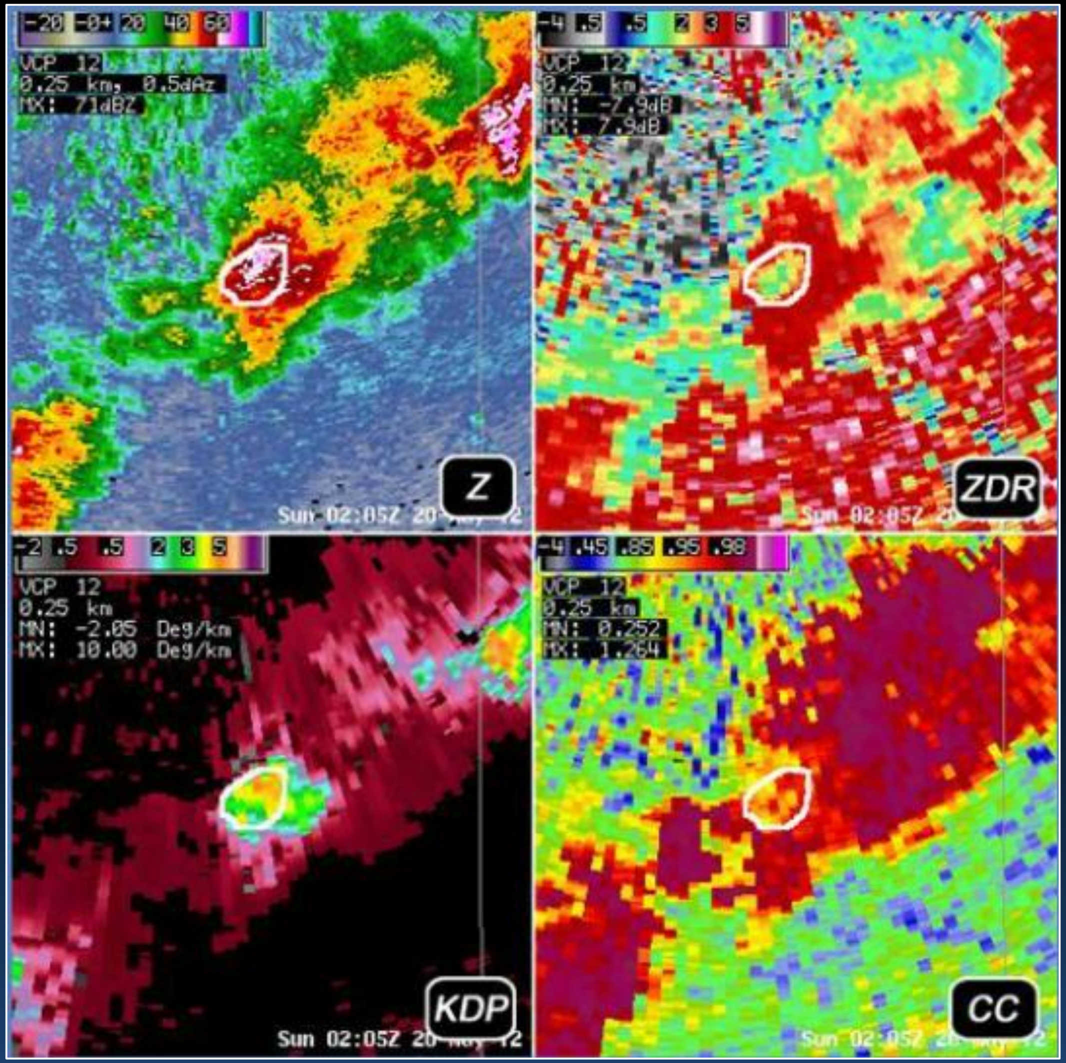
- Can vary significantly.
  - Dry Hail, KDP < 1 °/km
  - Hail mixed with Rain, KDP > 0.5 °/km
  - Melting Hail, KDP > 1.5-3 °/km

- KDP not computed when CC < 0.90.
  - Good indicator of golfball or larger hail.



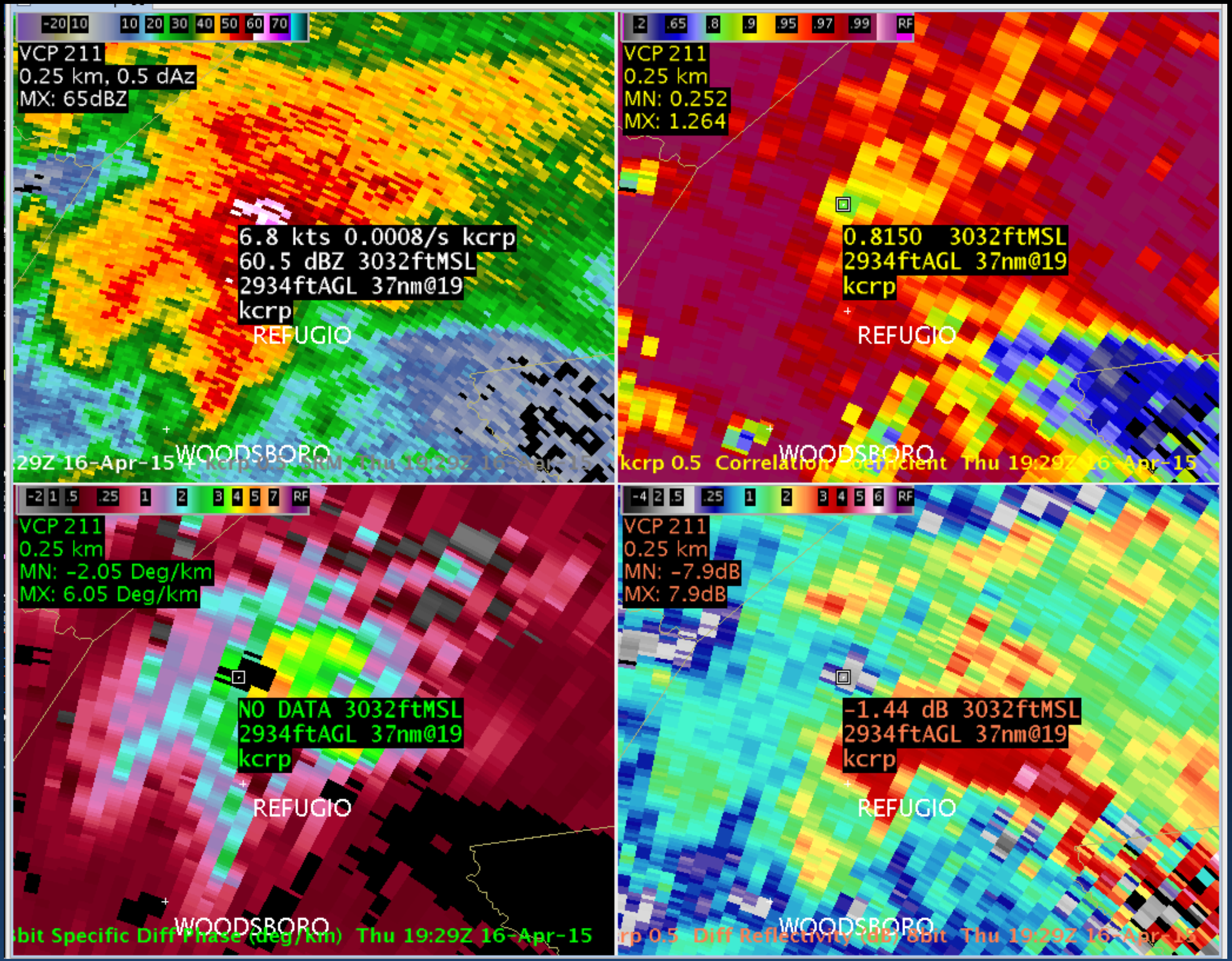
“Classic” Hail (1-1.75”) Mixed with Rain Dual-Pol Signature

- Z > 55 dBZ
- ZDR ~ 1-2 dB
  - Lower with pure hail.
- CC ~ 0.93 – 0.97
  - Higher with pure hail.
- KDP > 0.5 °/km
  - Can be lower with pure hail.



Significant (≥ 2”) Hail Dual-Pol Signature

- Z > 55 dBZ
- ZDR ~ 0 dB or lower
- CC < 0.90
- KDP not computed



Storm-Top Divergence:

| $V_{inbound}$ | + | $V_{outbound}$ | at storm summit

Witt and Nelson 1991 Study

- ΔV = 100 kts : 50% chance of ¼” hail
- ΔV = 130 kts : 50% chance of golfball hail
- ΔV = 200 kts : 50% chance of baseball hail

Blair et al. 2011 Study

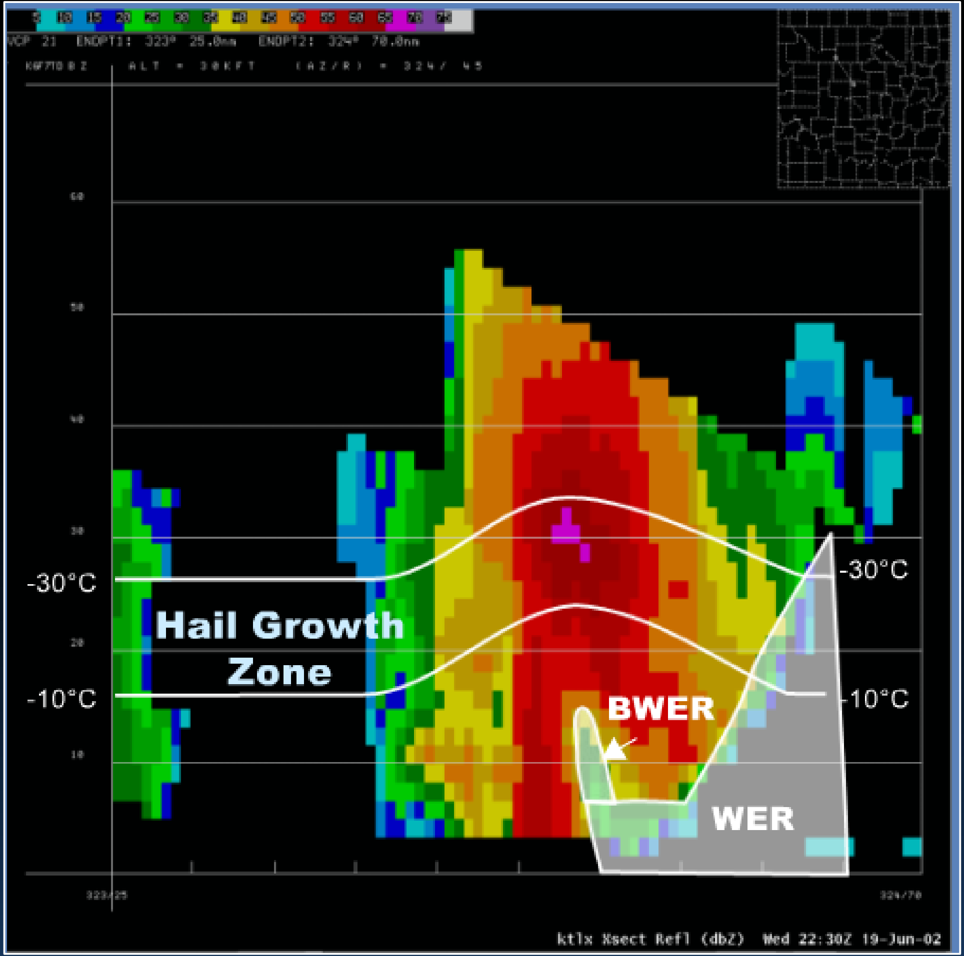
- ΔV 80-121 kts : ~Golfball size hail
- ΔV 117-171 kts : 4” size hail

WDTD Recommended Storm-Top Divergence Severe Hail Warning Criteria

Storm-Top Divergence	
Peak ΔV(kts)	**Max Hail Size (in.)**
70-102	Quarter (1")
103-134	Ping Pong (1 ½")
115-147	Golf ball (1 ¾")
130-162	Hen Egg/Lime (2")
159-192	Tennis Ball (2 ½")
174-207	Baseball (2 ¾")
233-267	Grapefruit (4")

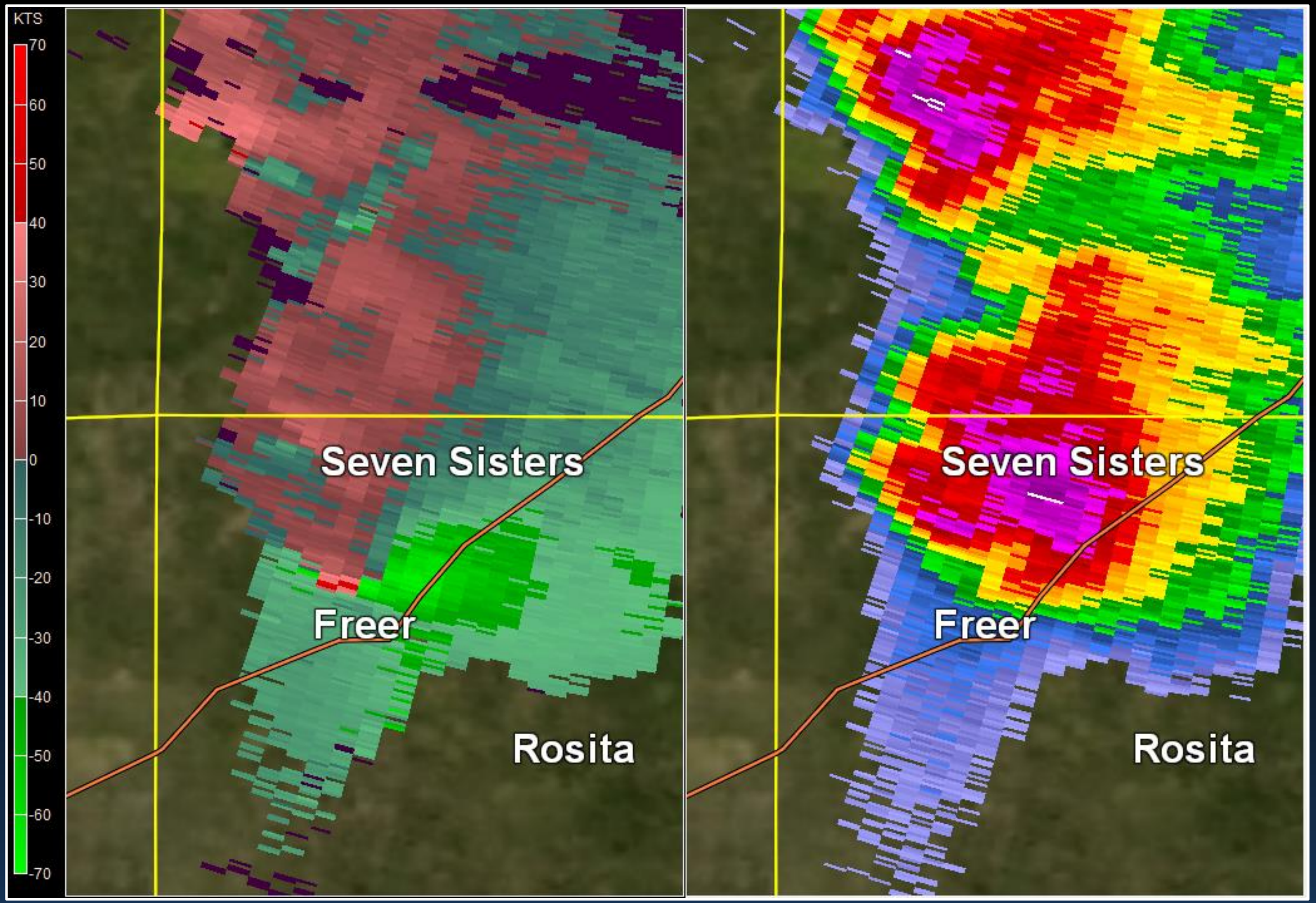
WER/BWER

- Region above WER/BWER is an area of rapid hail growth.
- Wide persistent WER/BWER enhances hailstone growth.
- If BWER present, then high likelihood of ≥ 2” hail.

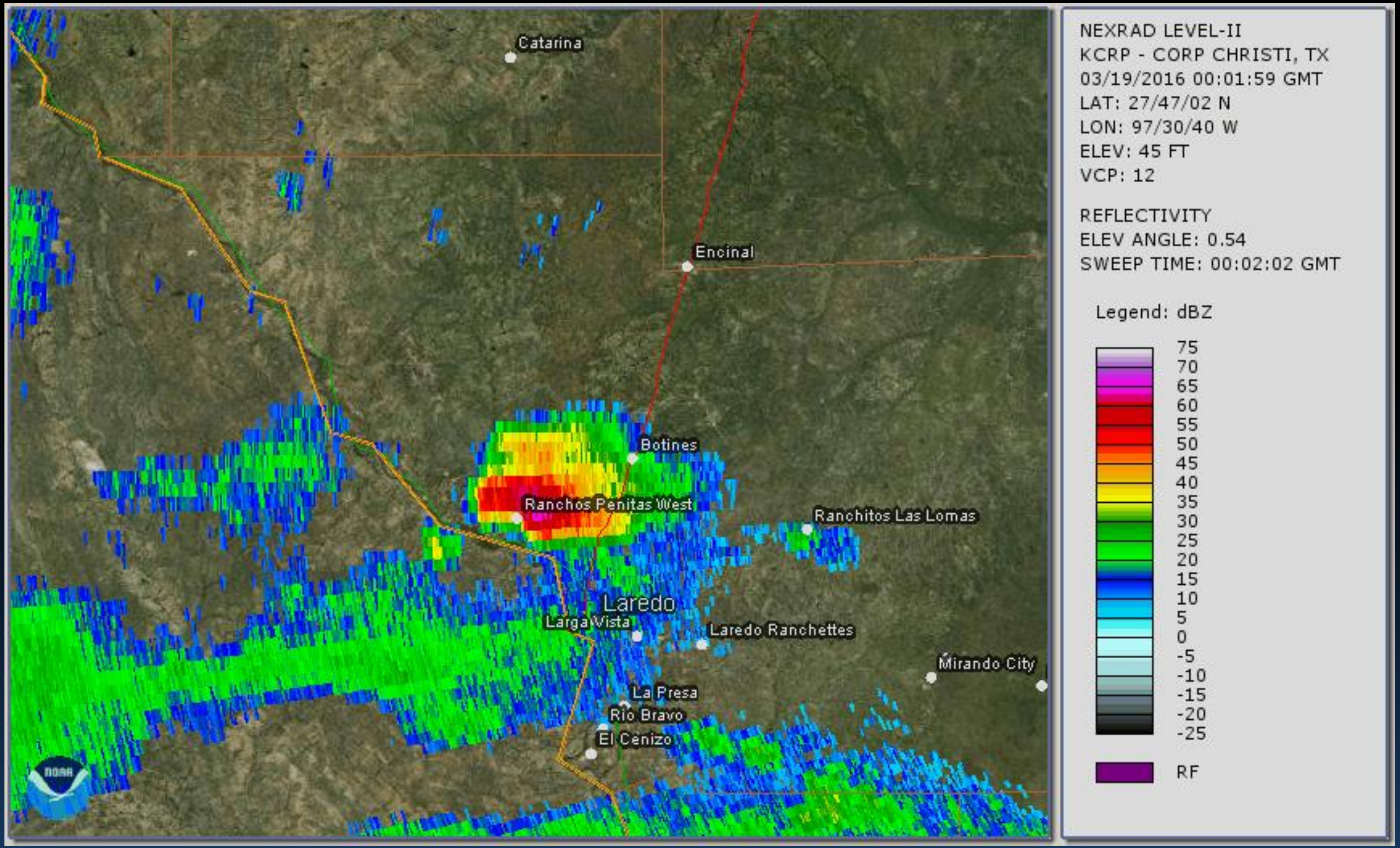


Mesocyclone

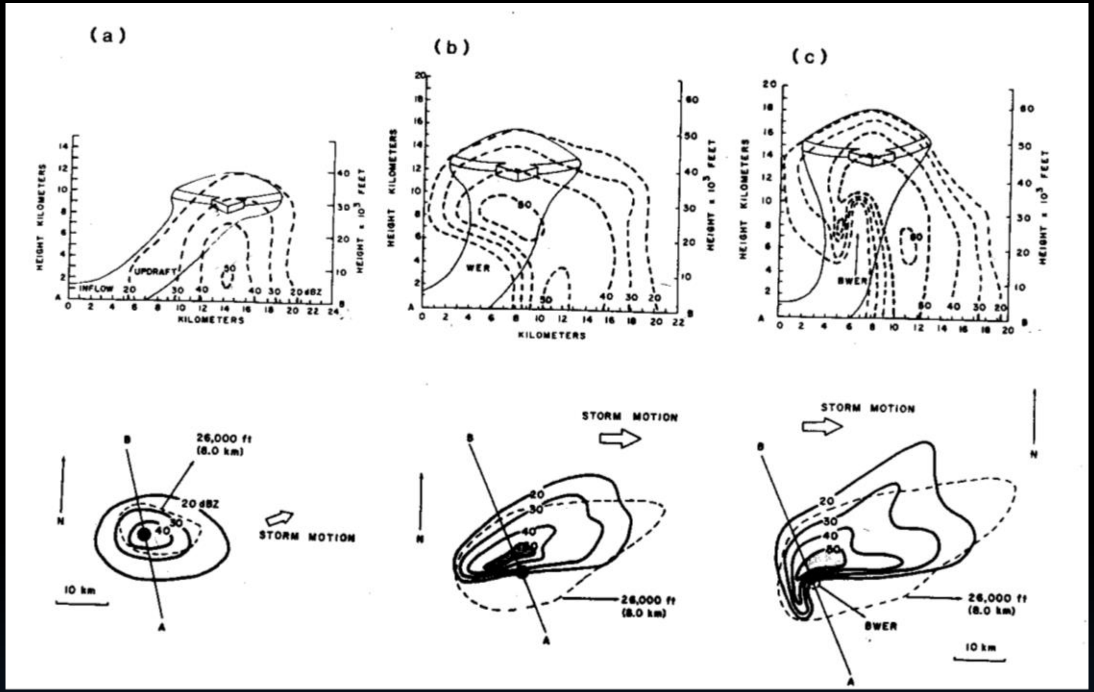
- Strong, persistent mesocyclone can be an indicator of severe hail.
- Supercells produce a high percentage of ≥ 2” hail.
- Supercells produce most ≥ 4” hail.



Left-movers can be prolific hail producers.



Lemon Technique for SVR Issuance



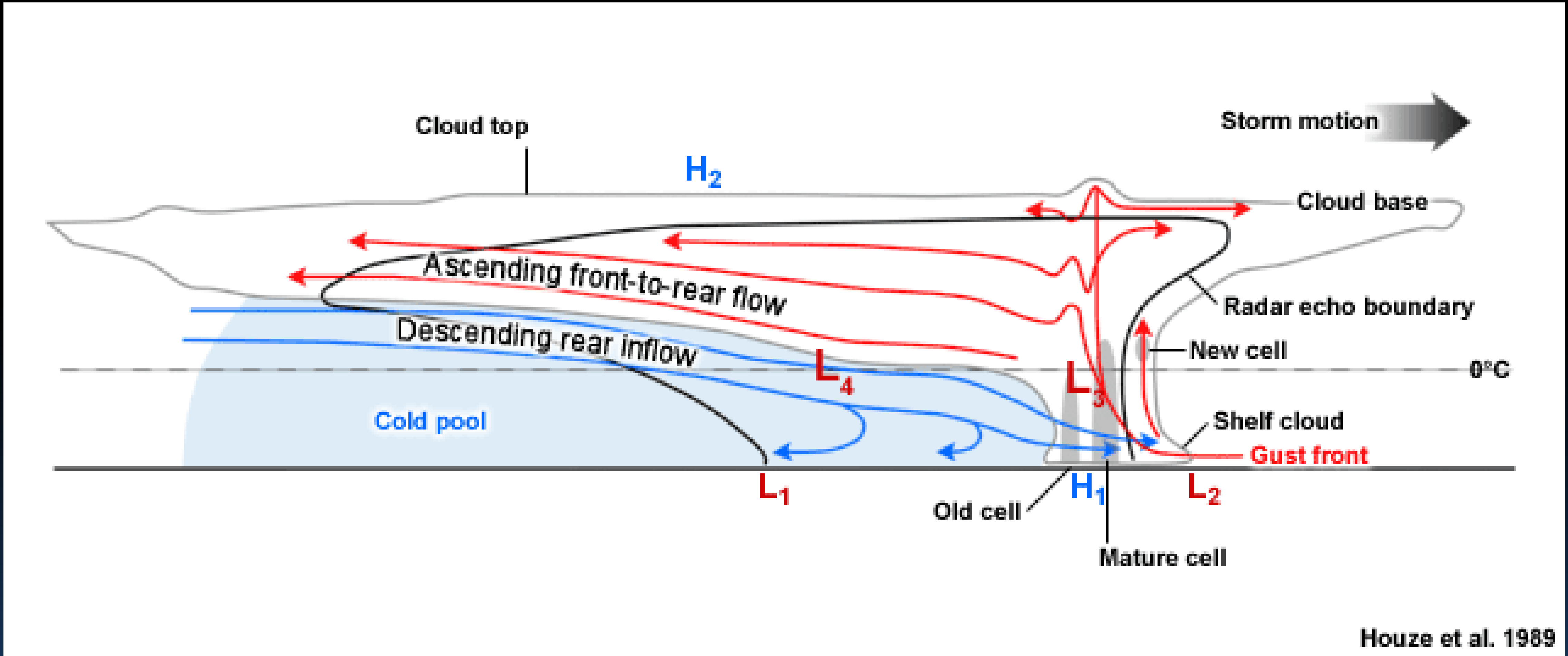
- 1). **50+ dBZ echo at 27+ kft AGL.**
- In the absence of #**1**, then **ALL** must occur:
  - **Z ≥ 46 dBZ 16-39 kft AGL.**
  - **WER extending ≥ 3.2 nm beyond the outer-edge of the low-level Z echo.**
  - **Highest echo top located on the storm flank possessing the overhang AND be above the low-level Z gradient between the echo core and echo edge or lie above the overhang itself.**

Severe Wind

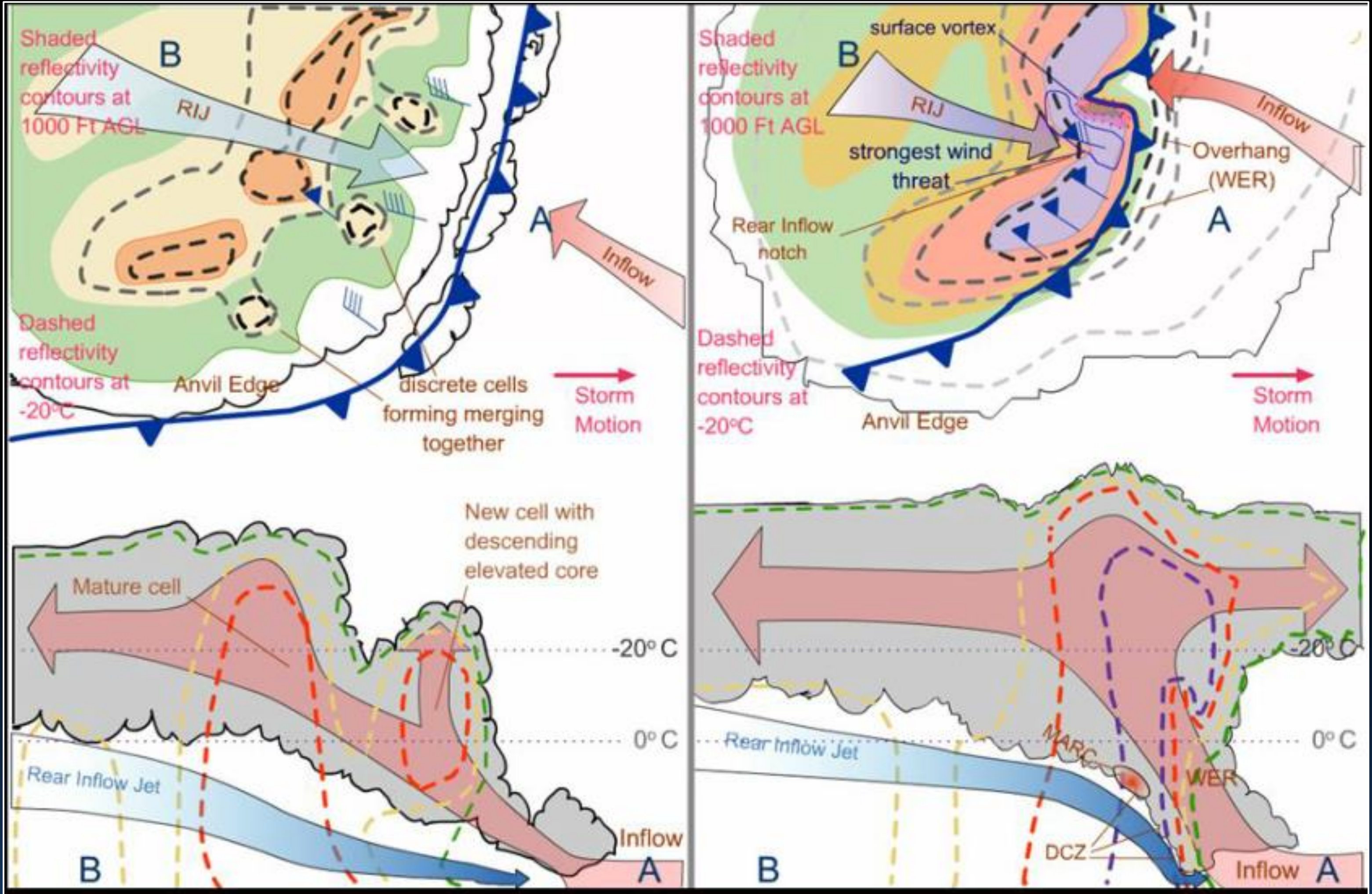
Severe Wind Indicators

- Bowing segment/line
  - Rear Inflow Notch (RIN)
  - Bookend Vortices
- WER/BWER
- “MARC” signature
- Descending core
- Diverging winds near the surface

Multicell/Linear (Squall Line) Conceptual Model



Quasi-Linear Convective System (QLCS) Structure



Lower probability of severe wind, tornado

Higher probability of severe wind, tornado

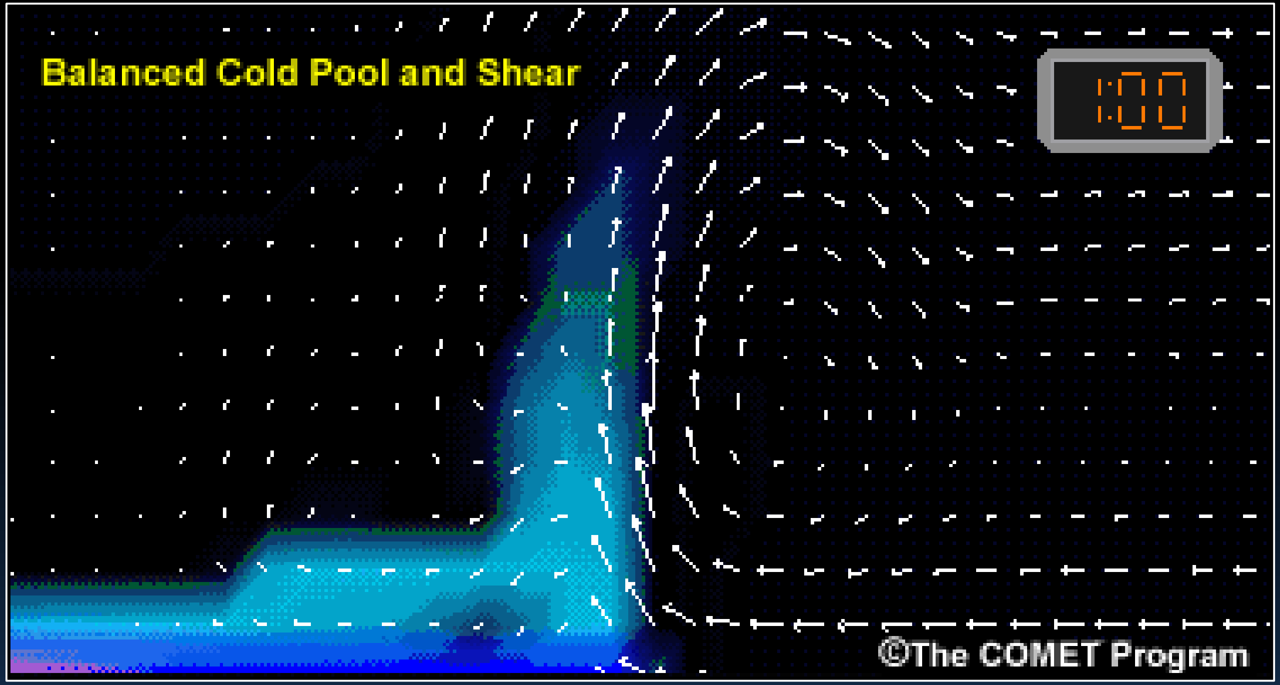
Balanced Cold Pool and Shear

- "Slab-like" lifting.
  - Deepest convection

- Damaging winds will be the strongest.

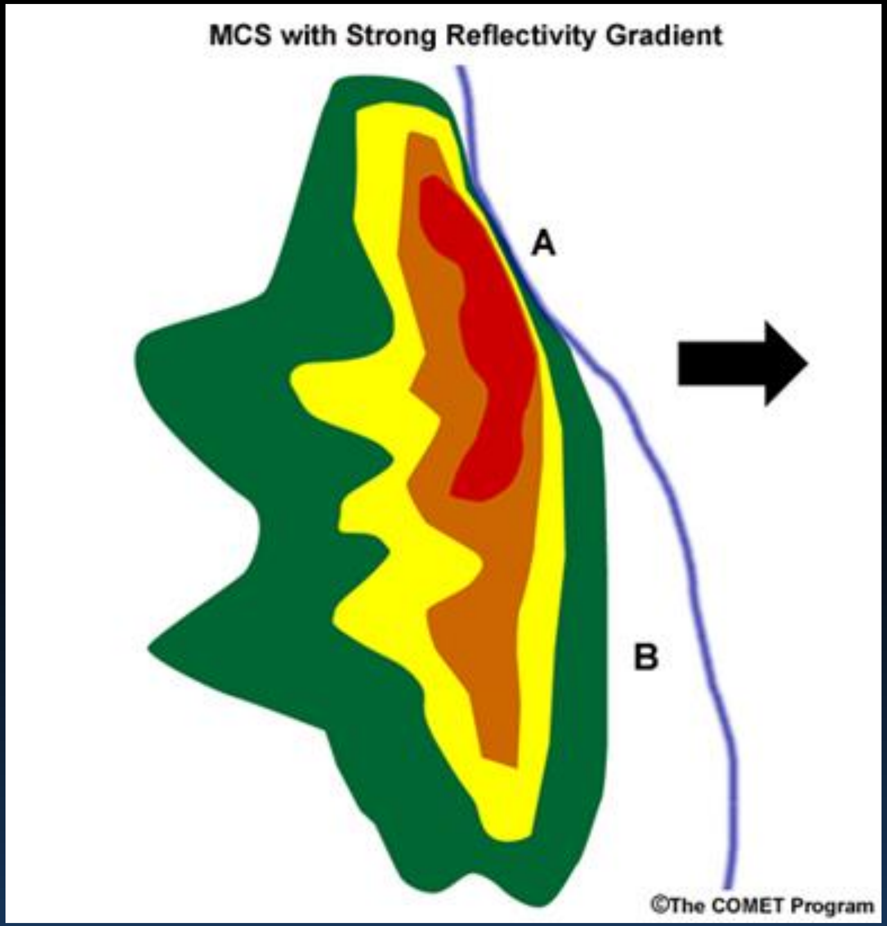
- Mesovortices very possible.

- Maintains itself longer.



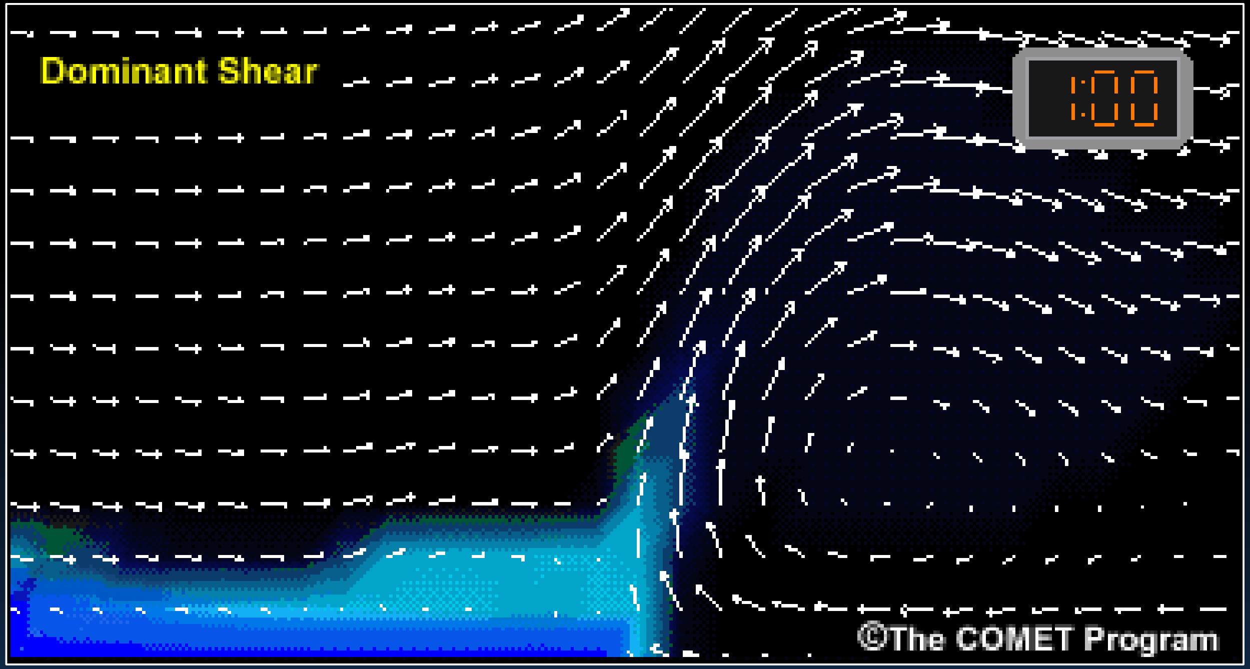
Other aspects of a severe bow echo

- Strong Z gradient along leading edge.
  - Location A
- Gust front speed matches system speed.
  - Location A
- Stronger winds at Location A.
- Cold pool and shear are in balance at Location A.



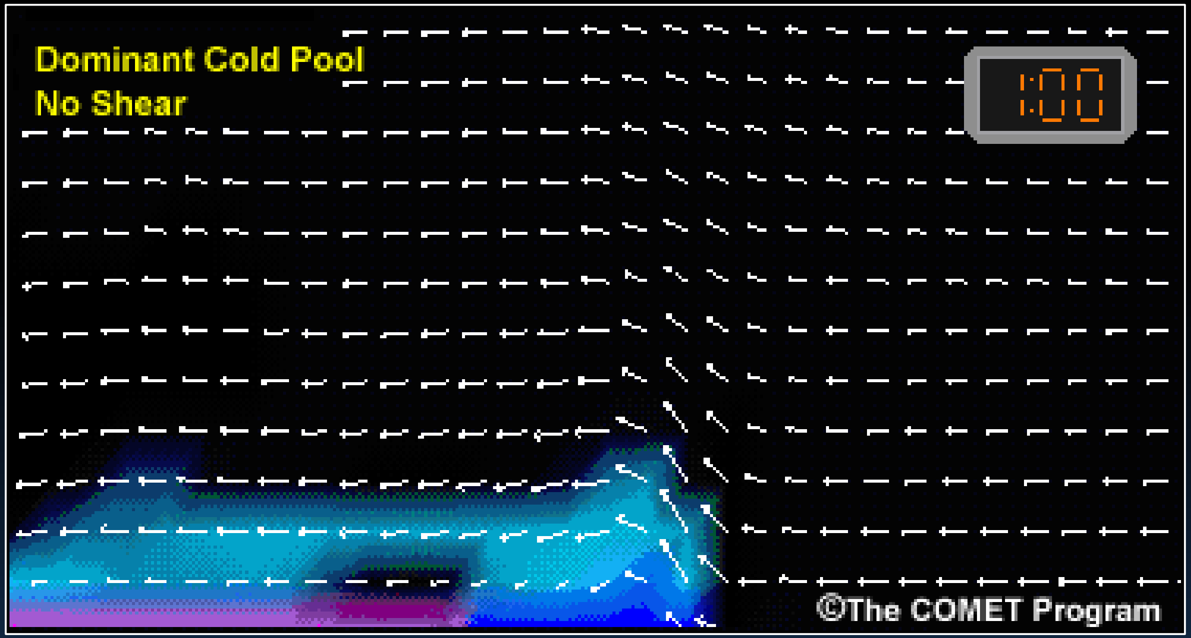
Shear-dominant

- More discreet cells possible.
  - Possible supercells
- Damaging winds possible.
- Mesovortices possible.



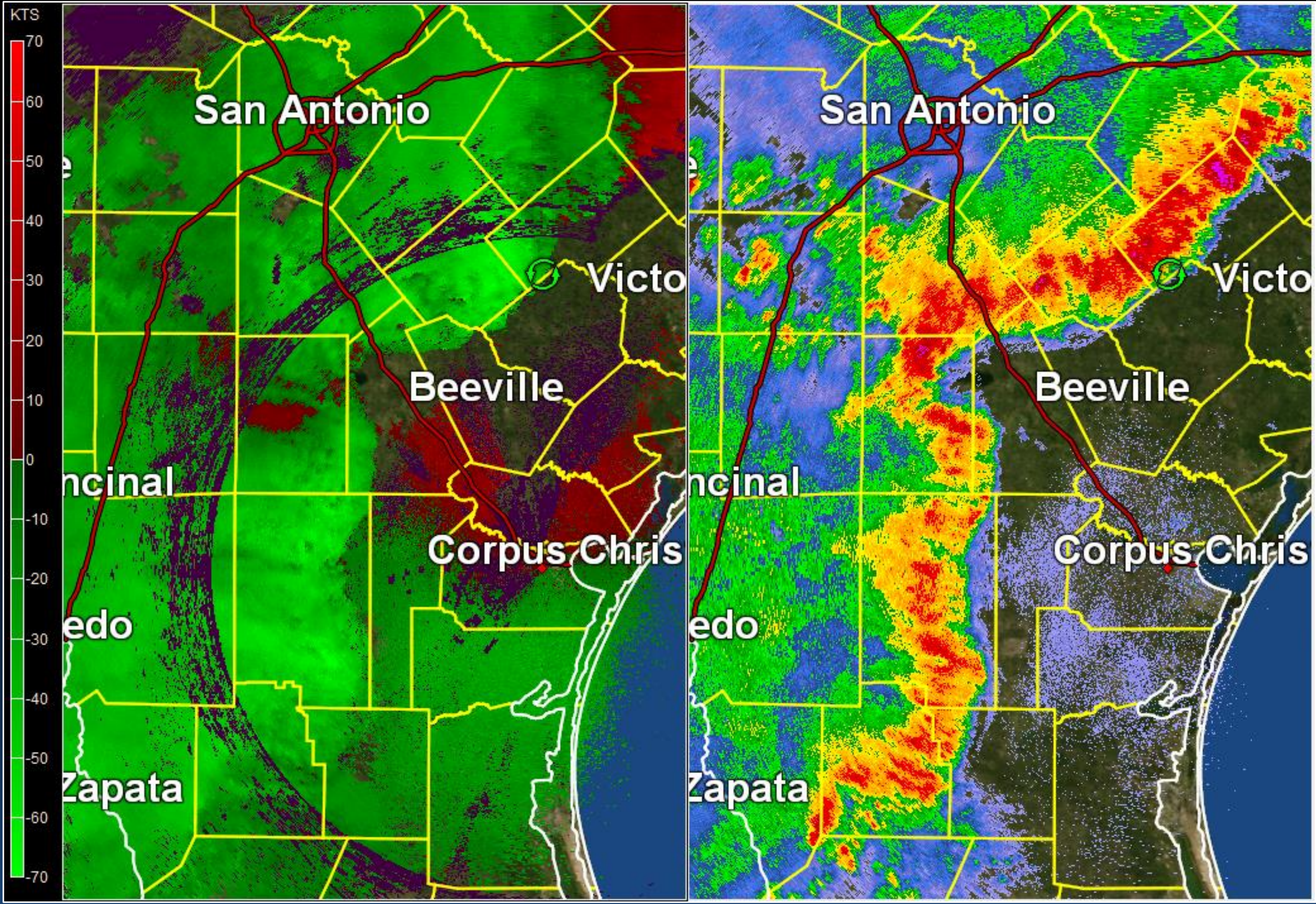
Cold-pool dominant

- More broken convection.
- Gust front outruns convection.
- Damaging wind possible but not as intense.
- Mesovortices much less likely.



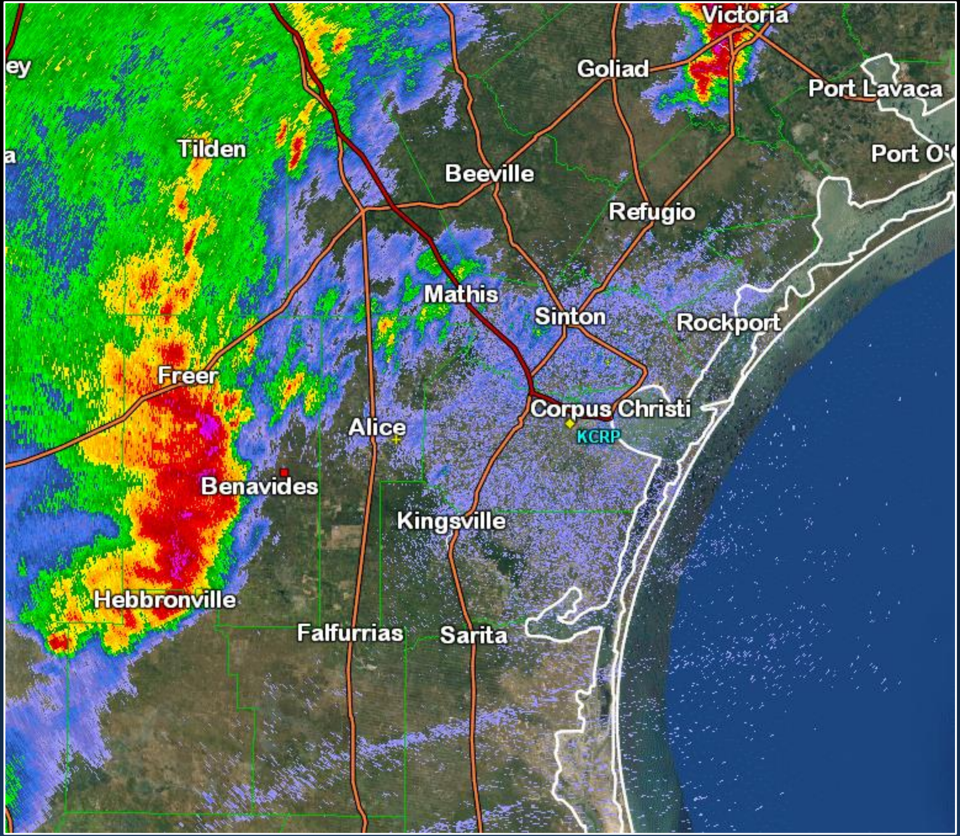
Bowing Segment or Line (Bow Echo,LEWP)

June 2, 2010 Double Squall Lines – 80-90 mph winds across Corpus Christi

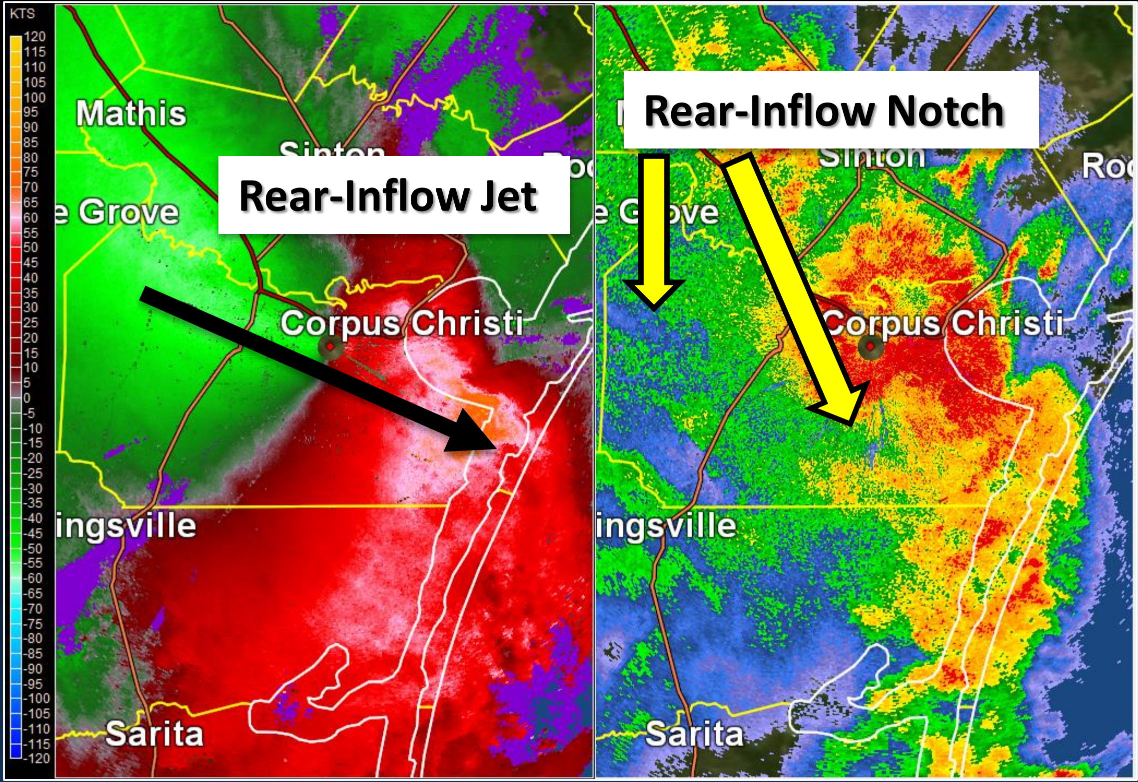


Severe Bow Echo
(Top 5 Severe Wind Event for Corpus Christi Int'l Airport)

Bow Echo March 18-19, 2016



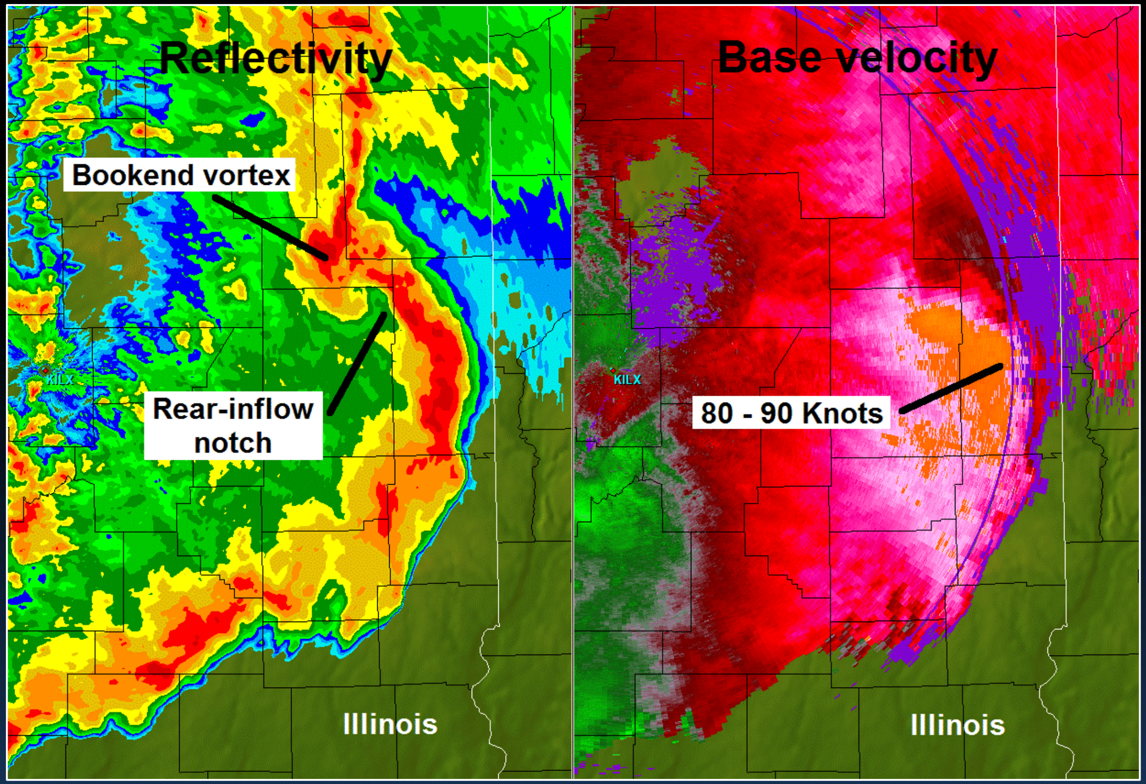
Rear-Inflow Notch (Widespread 55-70kts)



Rear Inflow Notch & Bookend Vortices

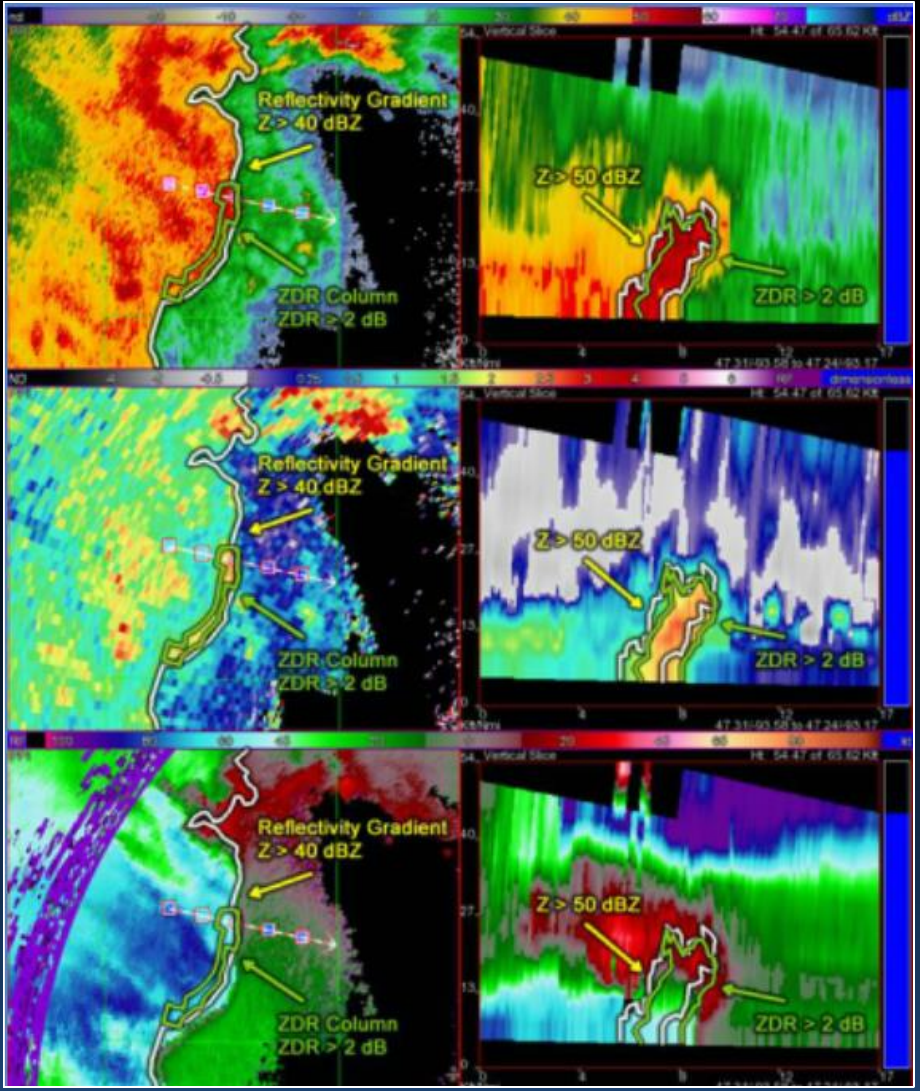
- RIN indicates the location of the RIJ.
  - "Evaporatively cooled" from dry air aloft.
  - Increased negative buoyancy.
  - Multiple RINs possible with larger systems.
  - Greater potential for strong winds.

- Presence of Bookend Vortices can enhance the RIJ.
  - Potential for stronger winds.

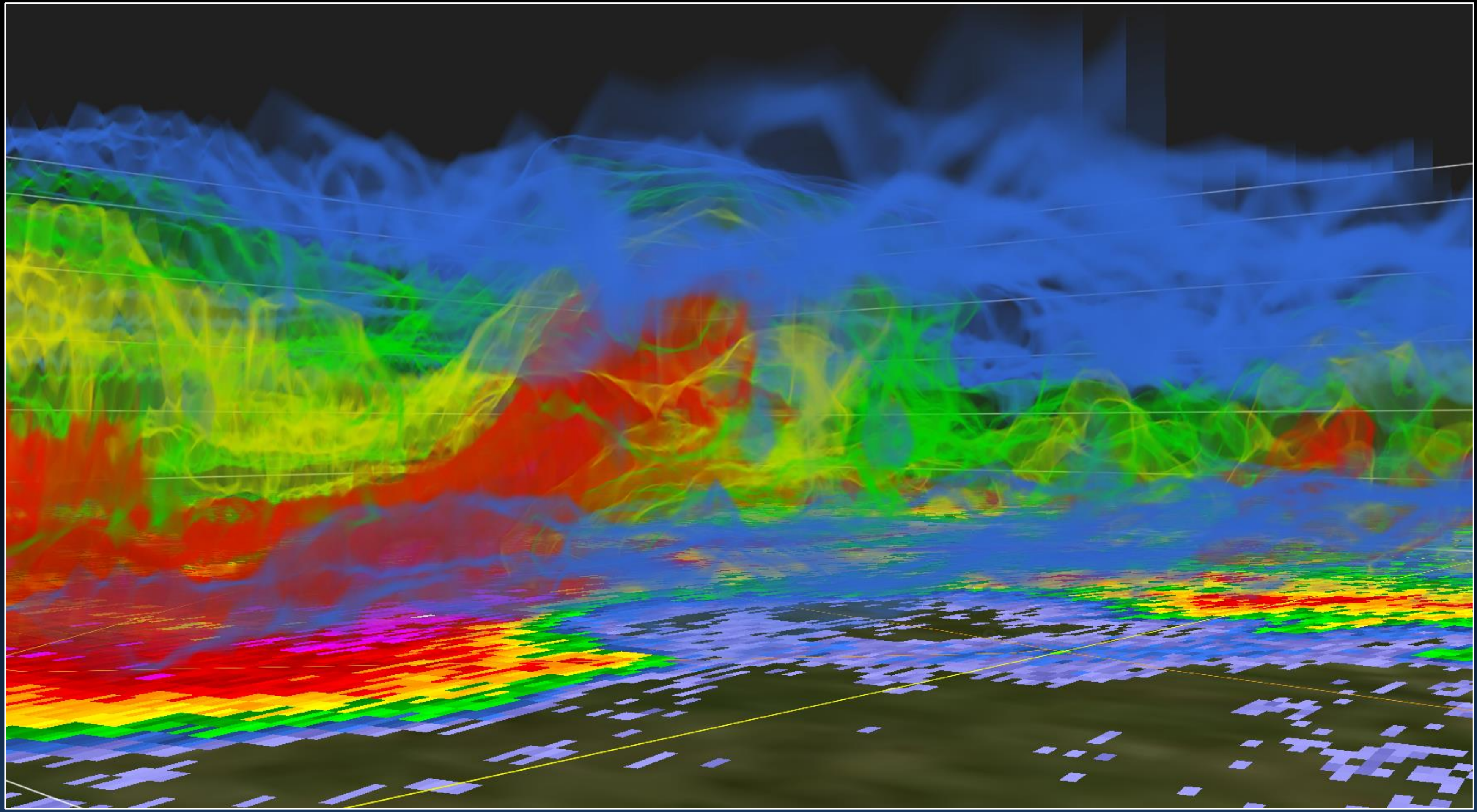


WER/BWER

- Can sometimes occur with mature systems when deep shear is present.
- Enhanced potential for damaging winds.
- Usually a tight low level Z gradient present.

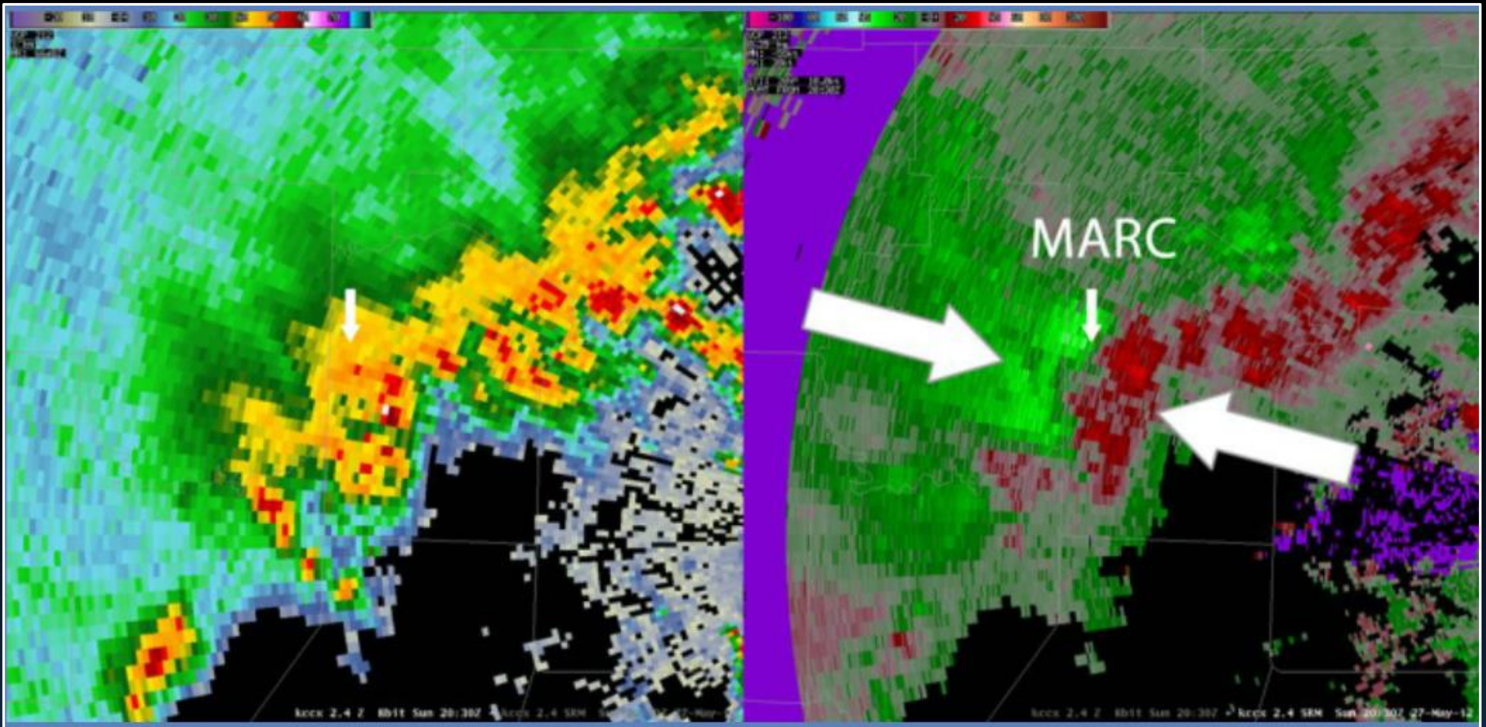


WER just north of Bow Echo Apex – March 19,2016
Effective Bulk Shear 40-50 kts



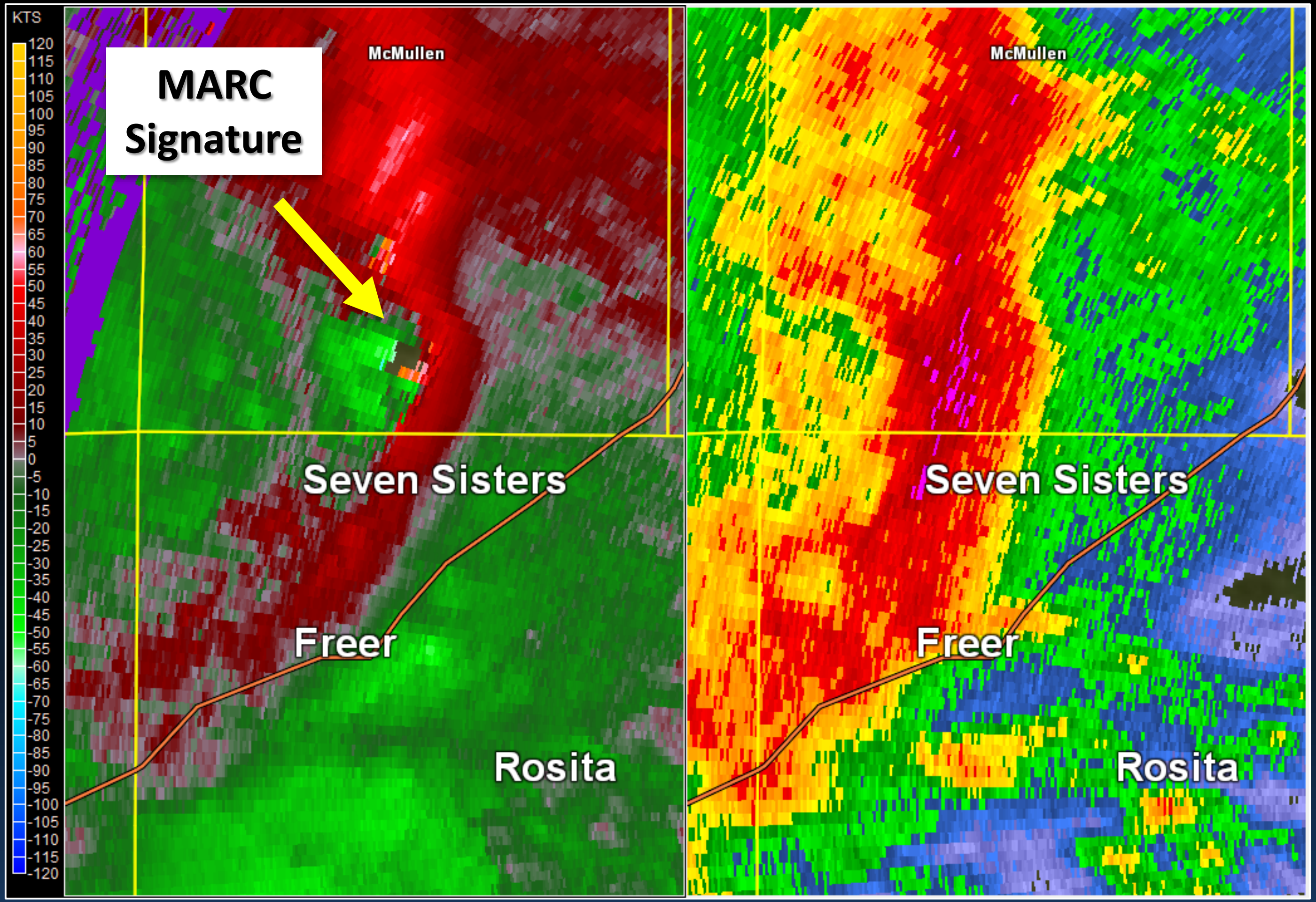
Mid-Altitude Radial Convergence (MARC) Signature

- Precursor to descent of Rear Inflow Jet.
- Persistent convergence > 50 kts at 3-7 km AGL.

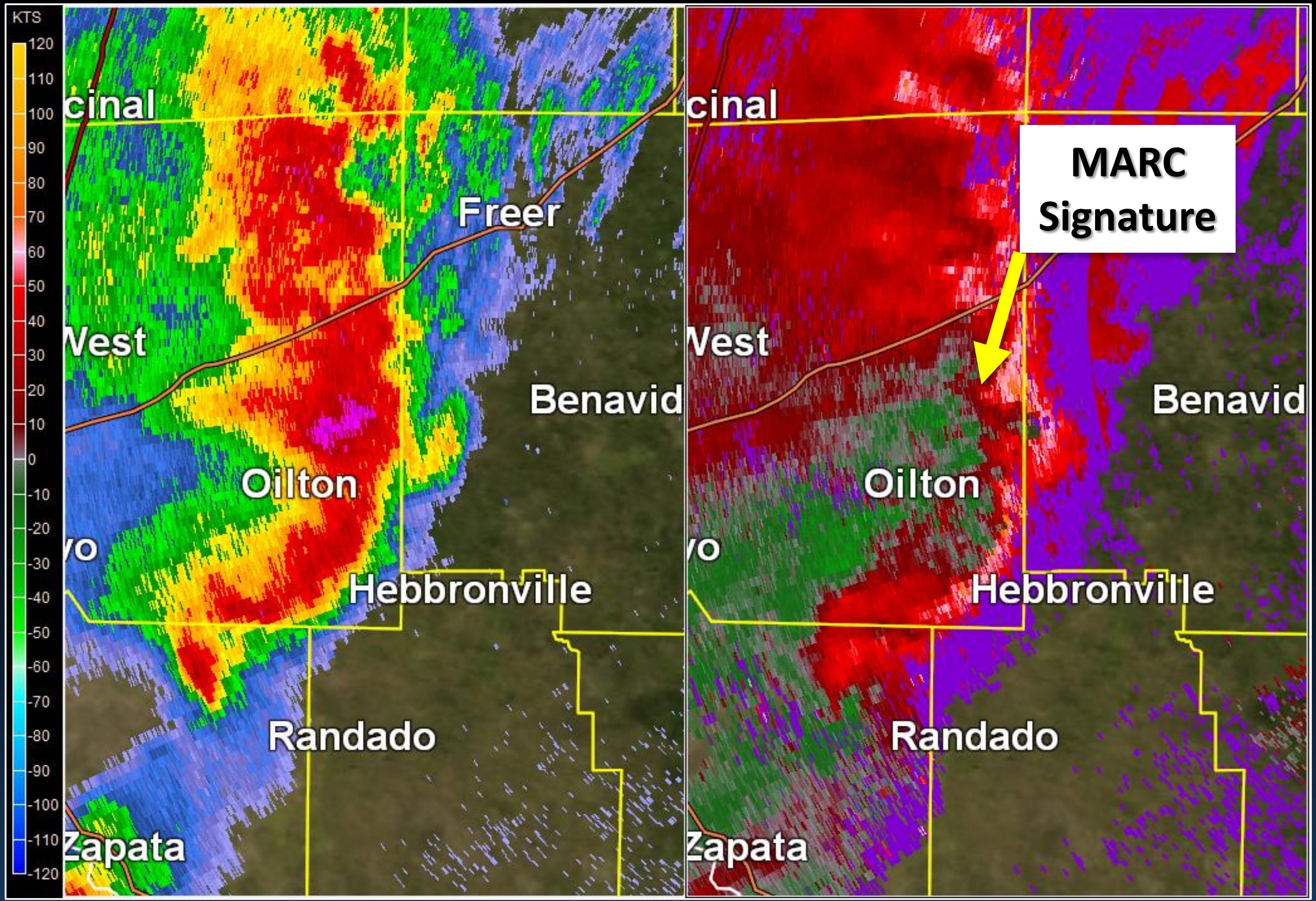


MARC Signature from KCCX on 2030 UTC 27 May 2012

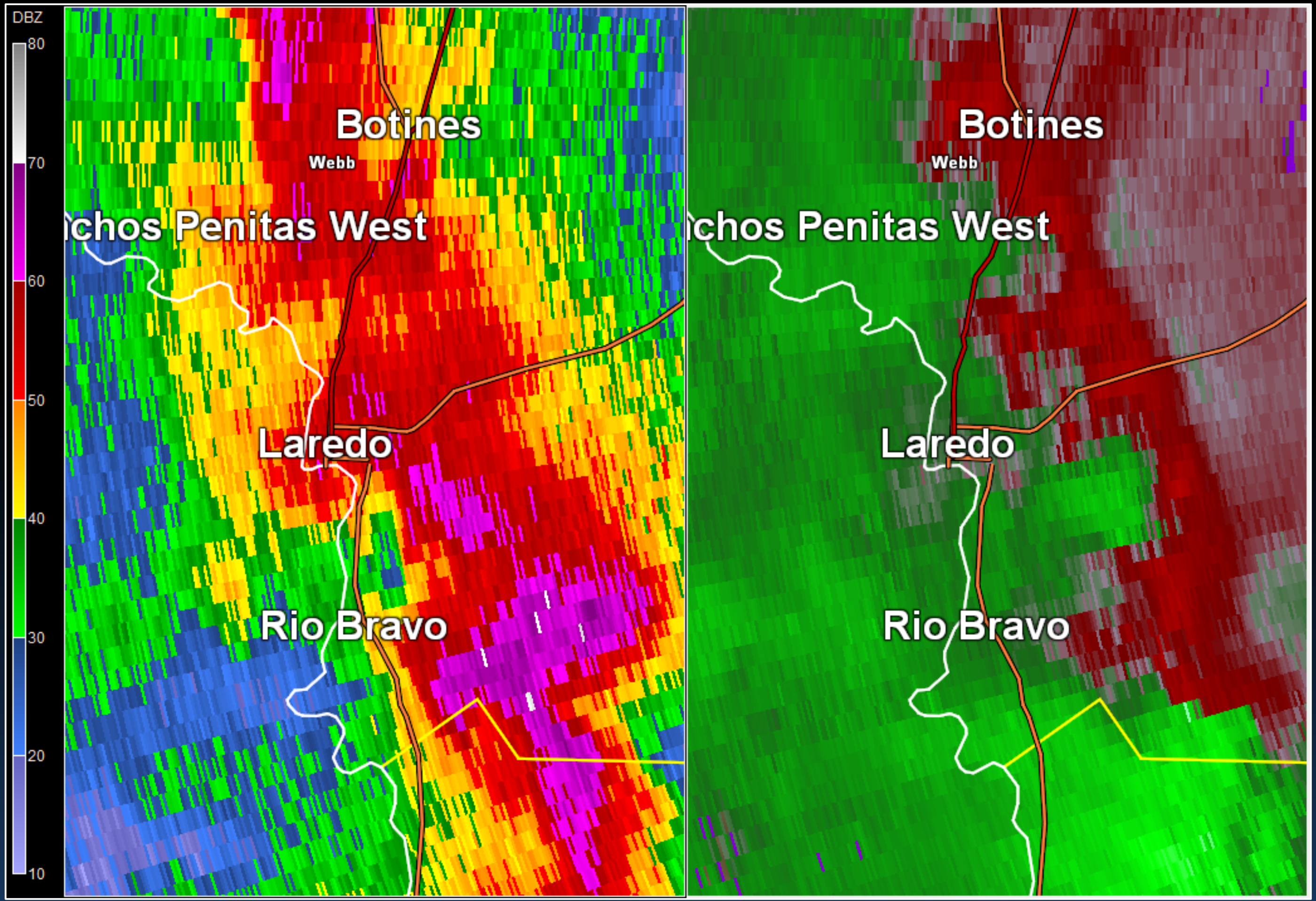
MARC Signature from January 9, 2011 QLCS



MARC Signature from March 18, 2016 Bow Echo

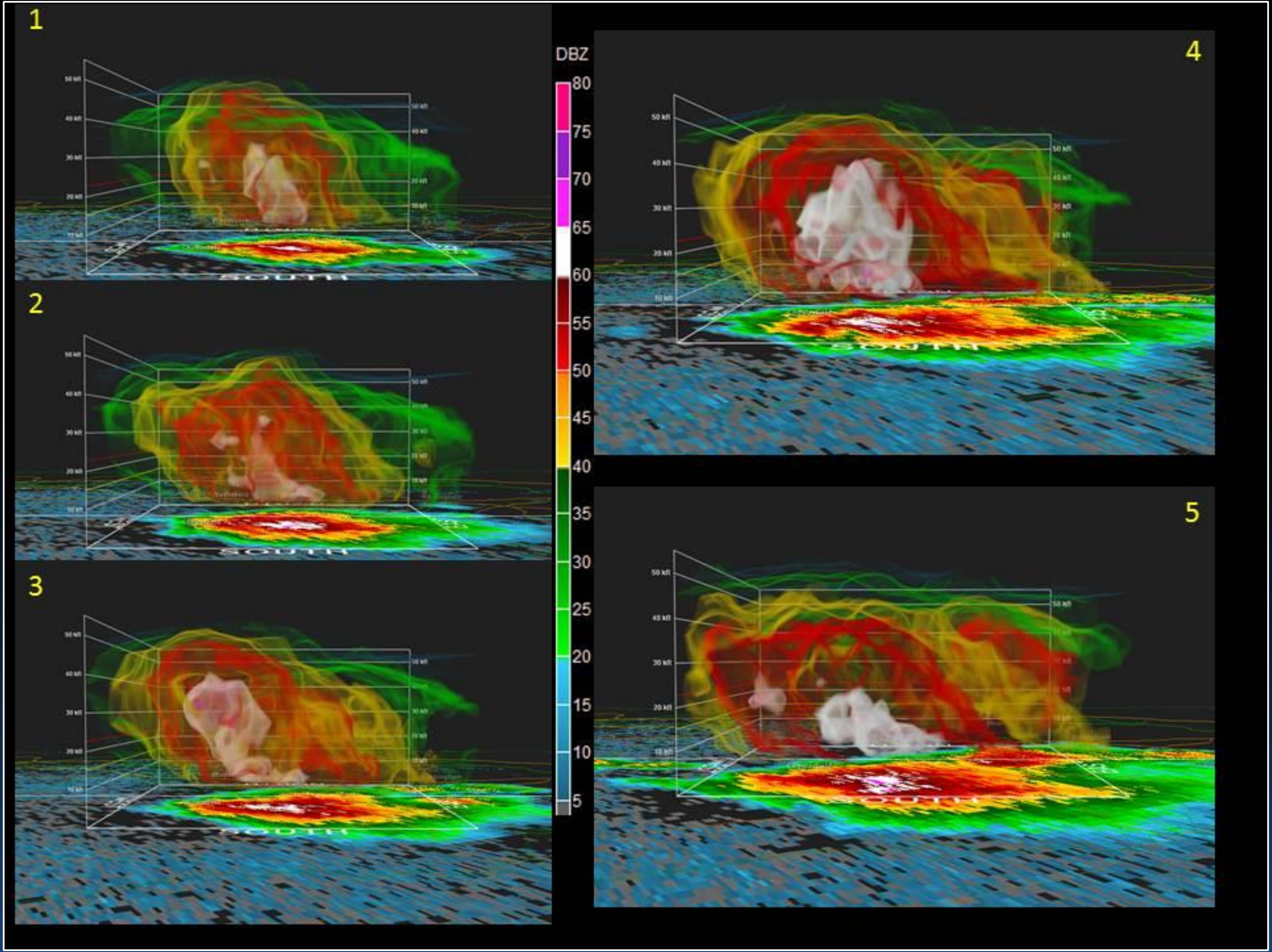


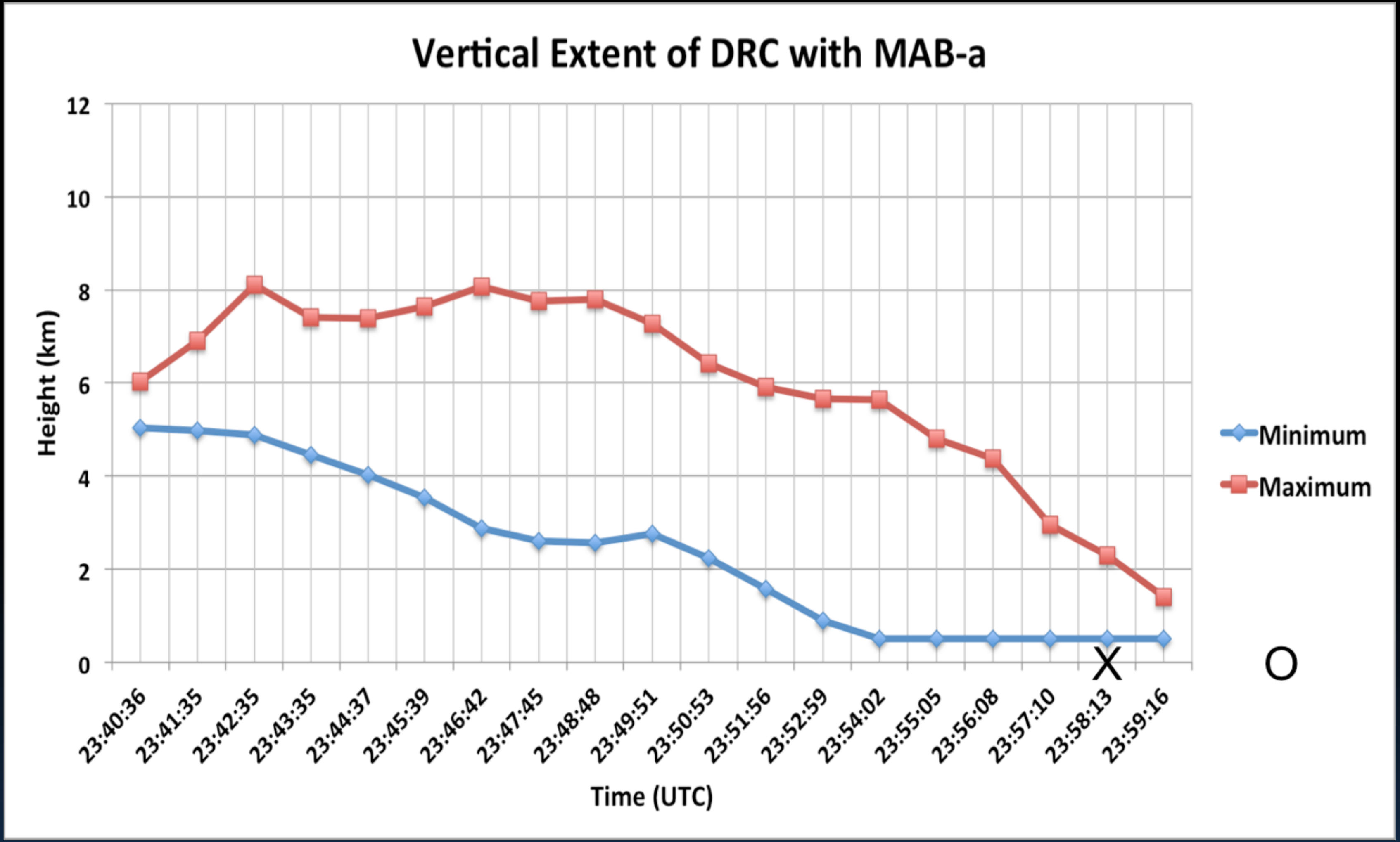
MARC Signature from Feb 20, 2017 QLCS



Descending Core – Single Cell

- Negative buoyancy due to:
  - Precipitation loading
  - Evaporative cooling
    - 0-3km layer $\Delta\theta_e$ > 25 °C
    - Maximum $\Delta\theta_e$ > 20 – 30 °K
  - Melting/Sublimation



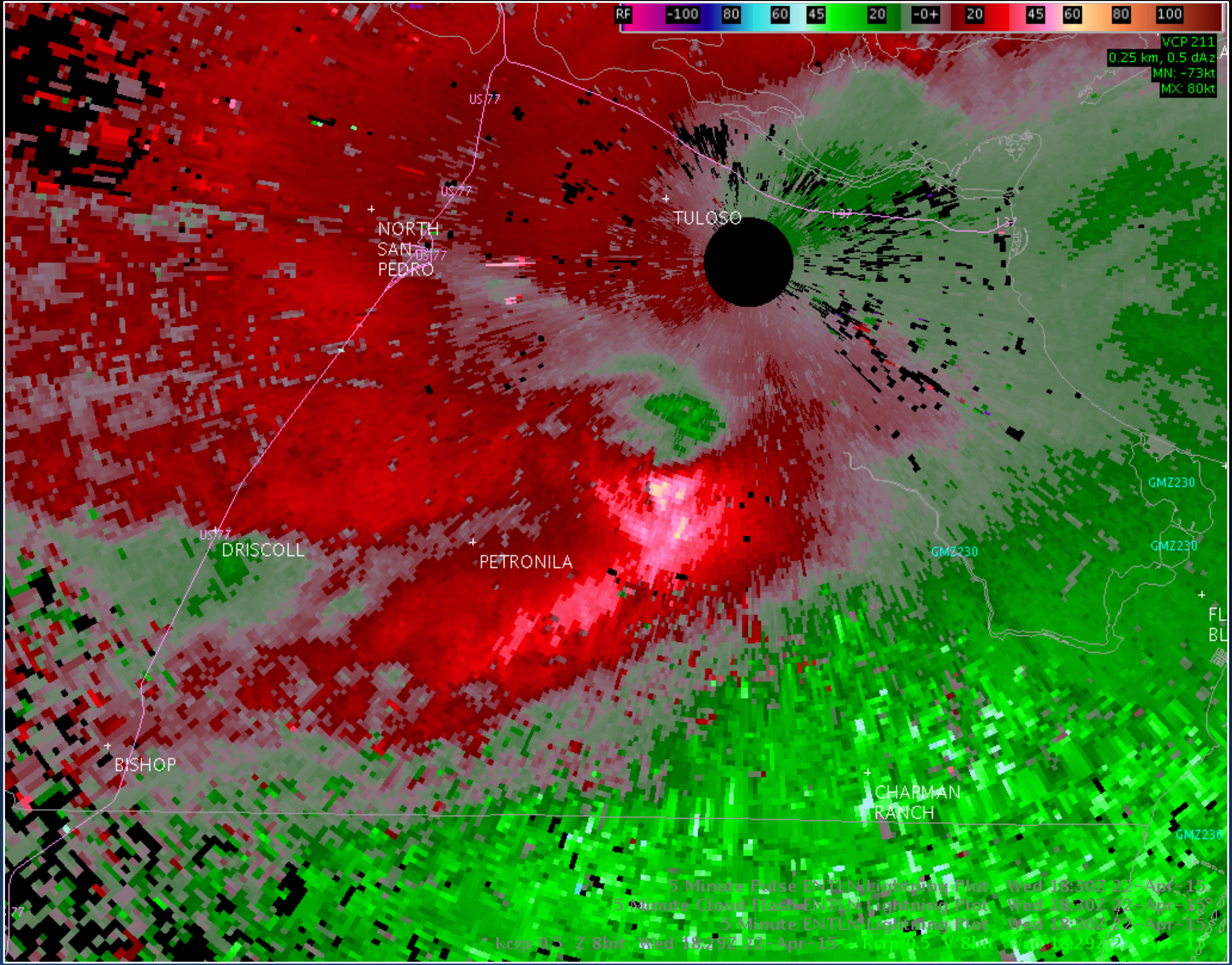


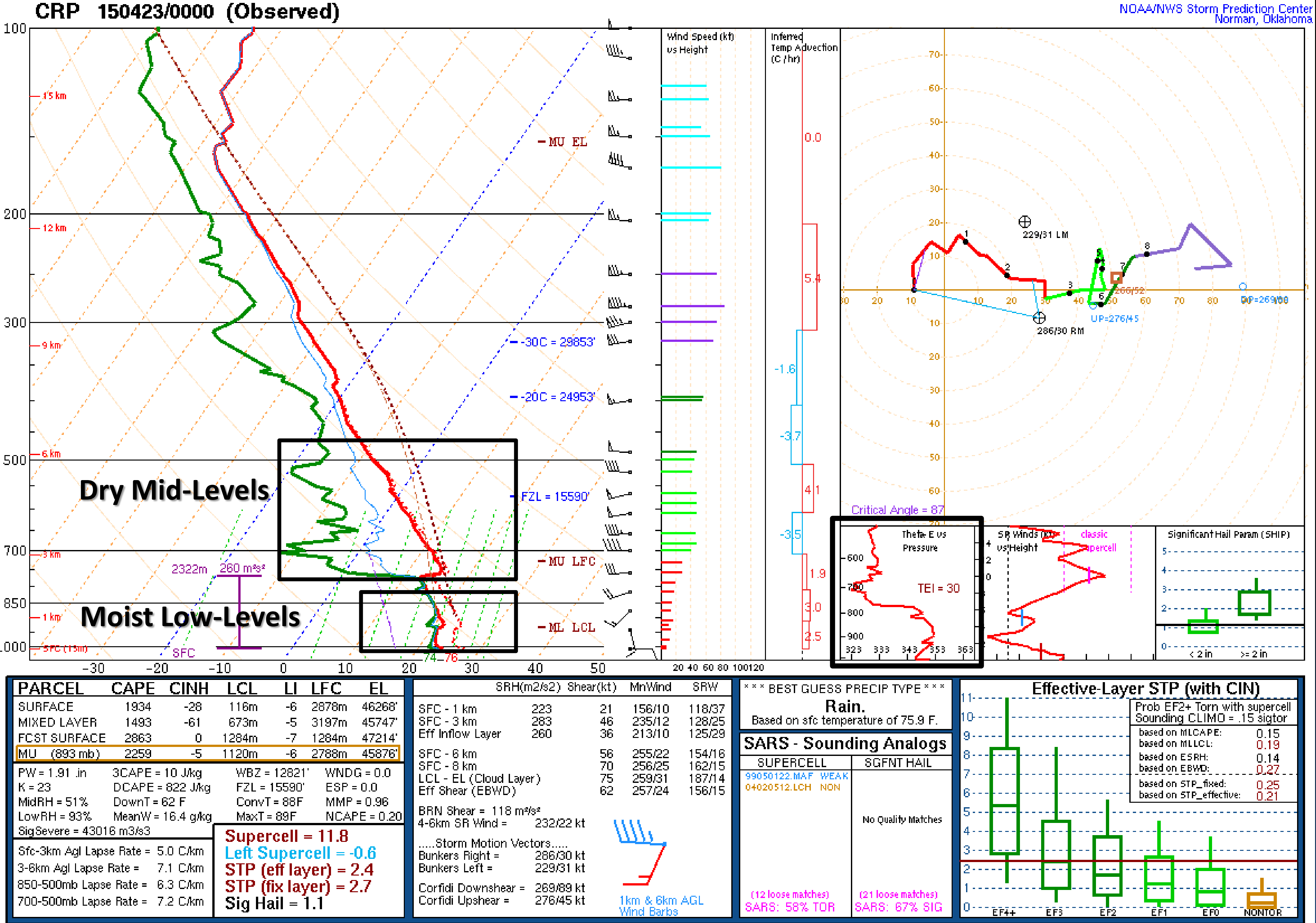
Evolution of the 65 dBZ isosurface associated with the severe downburst. The red line shows the maximum height (MSL) of the 65 dBZ isosurface, while the blue line shows the minimum height. X marks the initial sampling time of the near surface divergent signature, while the O marks the sampling time of the maximum base velocity (0002 UTC). Kuster et al. (2014)

Diverging Near-Surface Winds

- Downburst/Microburst spreading out as it encounters the surface.
- Little to no lead time.

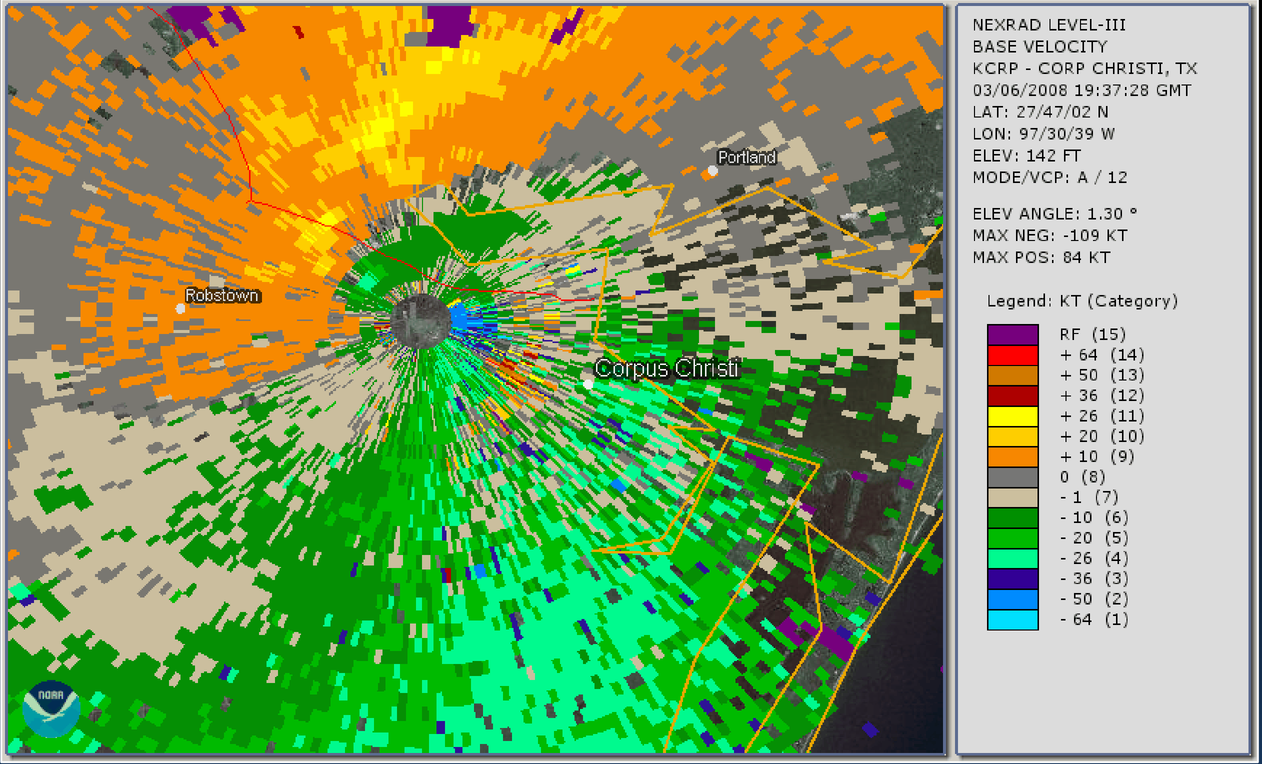
70+ mph east of Petronila – 4/22/15

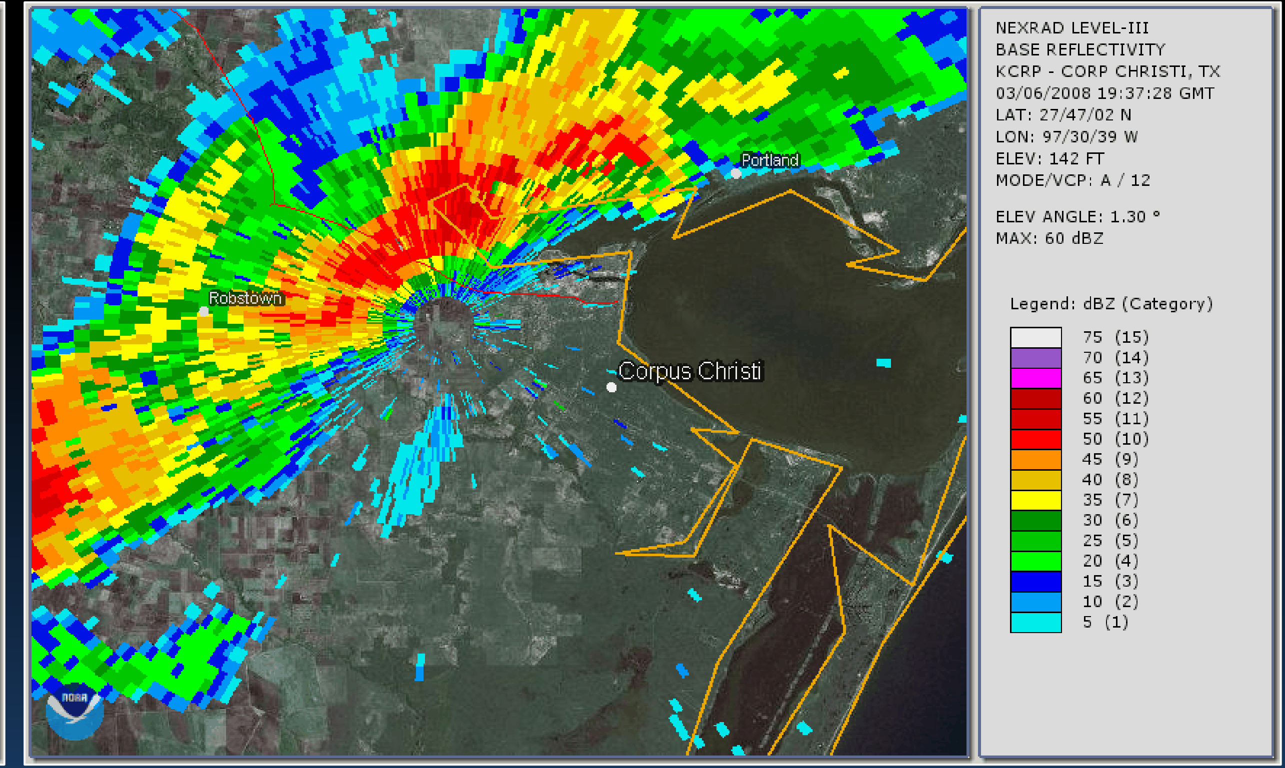



CRP 150423/0000 (Observed)
NOAA/NWS Storm Prediction Center
Norman, Oklahoma
Dry Mid-Levels
Moist Low-Levels
MU EL
-30C = 29853'
-20C = 24953'
FZL = 15590'
MU LFC
ML LCL
2322m 260 m²/s²
SFC
Wind Speed (kt) vs Height
Inferred Temp Advection (C / hr)
229/31 LM
286/30 RM
UP=276/45
DP=269/89
Critical Angle = 87
Theta-E vs Pressure
TEI = 30
SR Winds (kt) vs Height
classic supercell
Significant Hail Param (SHIP)
PARCEL CAPE CINH LCL LI LFC EL
SURFACE 1934 -28 116m -6 2878m 46268'
MIXED LAYER 1493 -61 673m -5 3197m 45747'
FCST SURFACE 2863 0 1284m -7 1284m 47214'
MU (893 mb) 2259 -5 1120m -6 2788m 45876'
PW = 1.91 in 3CAPE = 10 J/kg WBZ = 12821' WNDG = 0.0
K = 23 DCAPE = 822 J/kg FZL = 15590' ESP = 0.0
MidRH = 51% DownT = 62 F ConvT = 88F MMP = 0.96
LowRH = 93% MeanW = 16.4 g/kg MaxT = 89F NCAPE = 0.20
SigSevere = 43016 m3/s3
Sfc-3km Agl Lapse Rate = 5.0 C/km
3-6km Agl Lapse Rate = 7.1 C/km
850-500mb Lapse Rate = 6.3 C/km
700-500mb Lapse Rate = 7.2 C/km
Supercell = 11.8
Left Supercell = -0.6
STP (eff layer) = 2.4
STP (fix layer) = 2.7
Sig Hail = 1.1
SRH(m2/s2) Shear(kt) MnWind SRW
SFC - 1 km 223 21 156/10 118/37
SFC - 3 km 283 46 235/12 128/25
Eff Inflow Layer 260 36 213/10 125/29
SFC - 6 km 56 255/22 154/16
SFC - 8 km 70 256/25 162/15
LCL - EL (Cloud Layer) 75 259/31 187/14
Eff Shear (EBWD) 62 257/24 156/15
BRN Shear = 118 m²/s²
4-6km SR Wind = 232/22 kt
.....Storm Motion Vectors.....
Bunkers Right = 286/30 kt
Bunkers Left = 229/31 kt
Corfidi Downshear = 269/89 kt
Corfidi Upshear = 276/45 kt
1km & 6km AGL Wind Barbs
* * * BEST GUESS PRECIP TYPE * * *
Rain.
Based on sfc temperature of 75.9 F.
SARS - Sounding Analogs
SUPERCELL SGFNT HAIL
99050122.MAF WEAK
04020512.LCH NON
No Quality Matches
(12 loose matches) (21 loose matches)
SARS: 58% TOR SARS: 67% SIG
Effective-Layer STP (with CIN)
Prob EF2+ Torn with supercell
Sounding CLIMO = .15 sigtor
based on MLCAPE: 0.15
based on MLLCL: 0.19
based on ESRH: 0.14
based on EBWD: 0.27
based on STP_fixed: 0.25
based on STP_effective: 0.21
EF4+ EF3 EF2 EF1 EF0 NONTOR

Rear Flank Downdraft from a Supercell

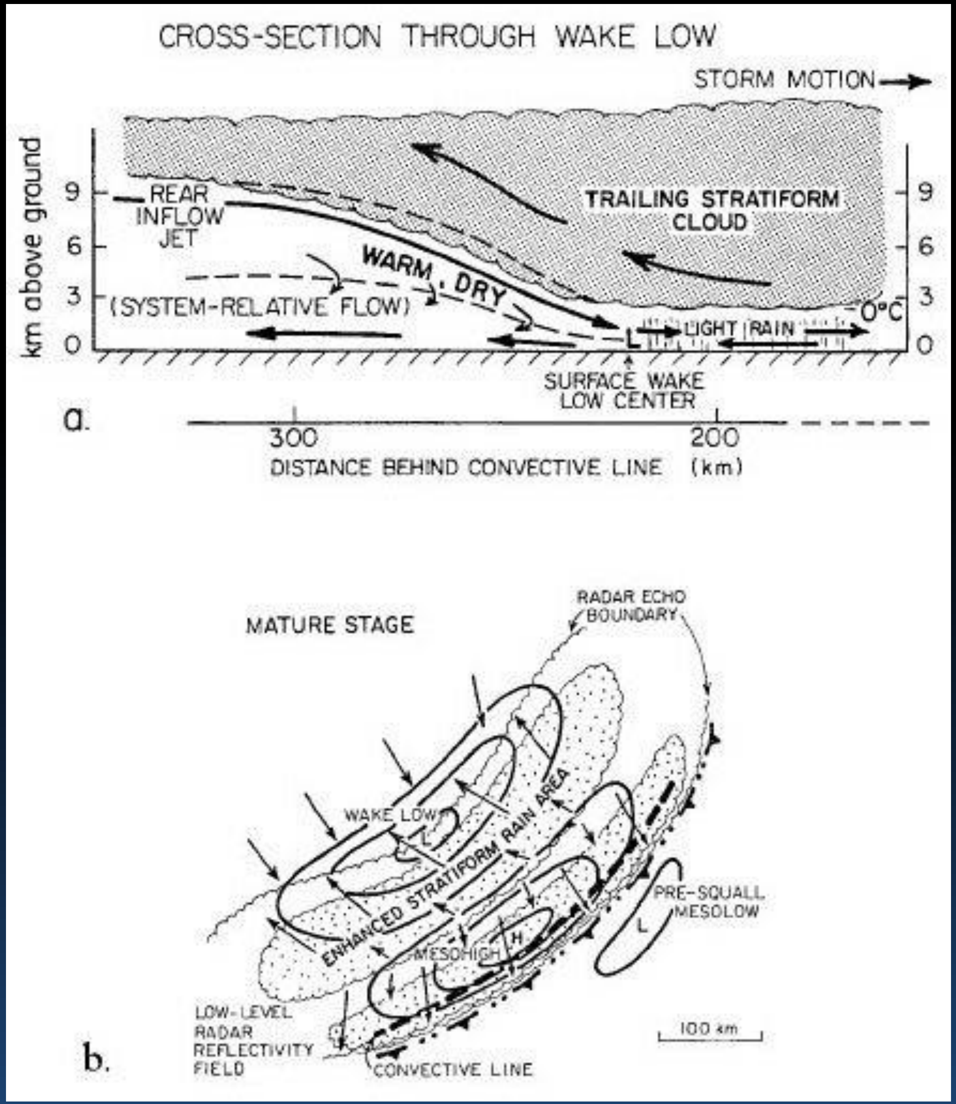
67 mph wind gust at KCRP on 3/6/08



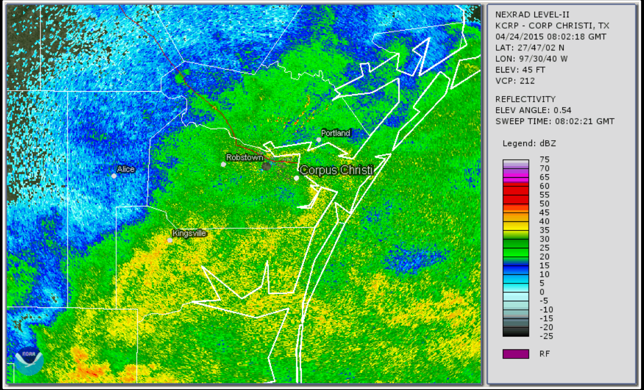


"Wake Low" Severe Winds

- Two main theories:
  - Adiabatic Warming/Drying due to Subsidence.
  - Gravity Wave Formation.
- Maximized on trailing edge of stratiform pcpn.
- Falling pressures produce the strong winds.
  - Usually 35-50 mph winds.
  - Can reach severe levels.



Coastal Bend “Wake Low” High Wind Event – April 24, 2015

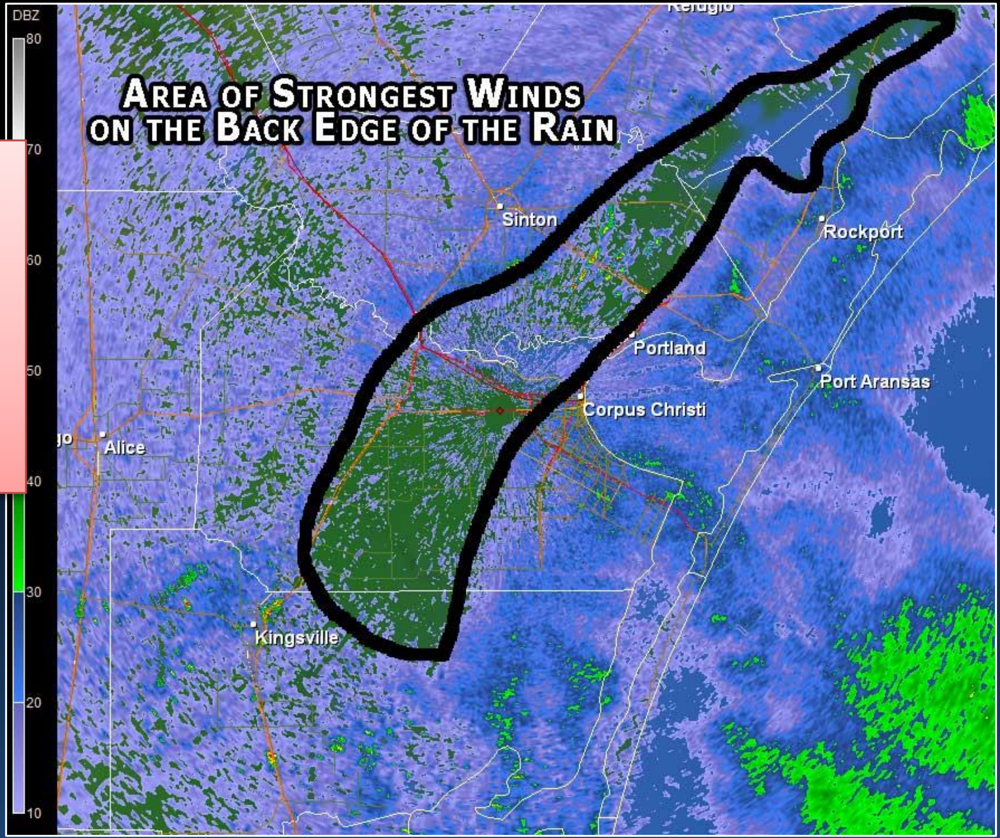


61 mph wind gust at KCRP

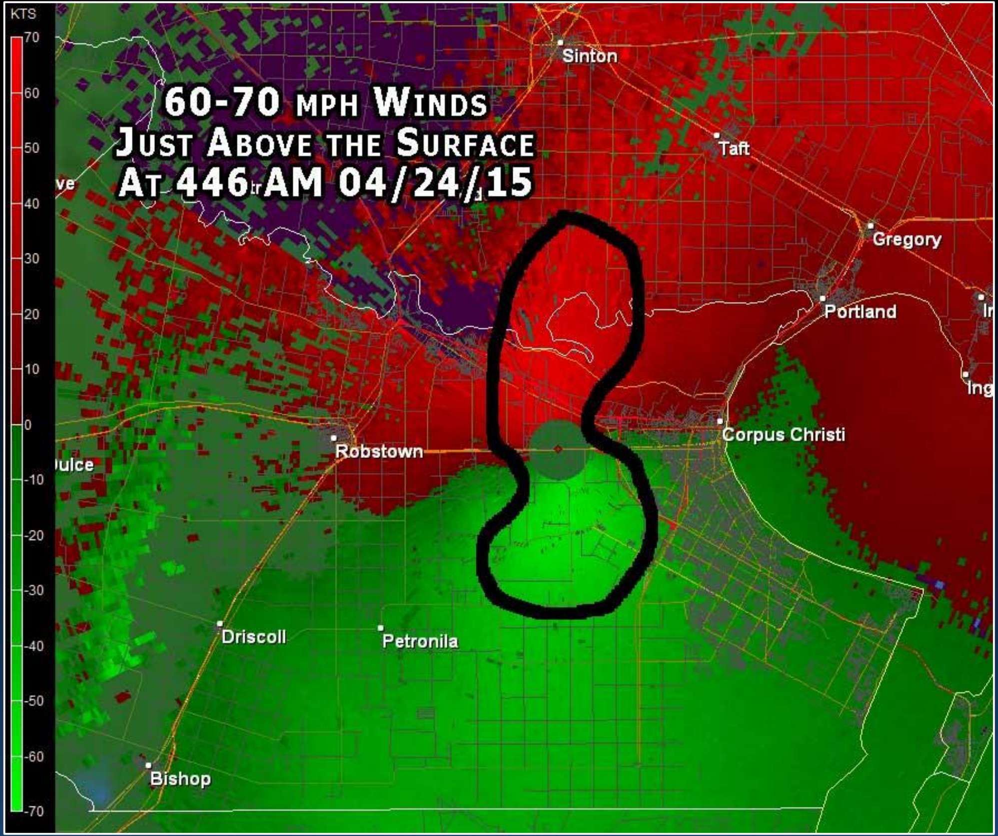
90 mph winds several hundred feet above the surface at the peak of this event!

Pressure falls 5-7 mbs.

KCRP Z at 505 AM showing rapid drying



KCRP V at 446 AM showing 60-70 mph winds just above the surface

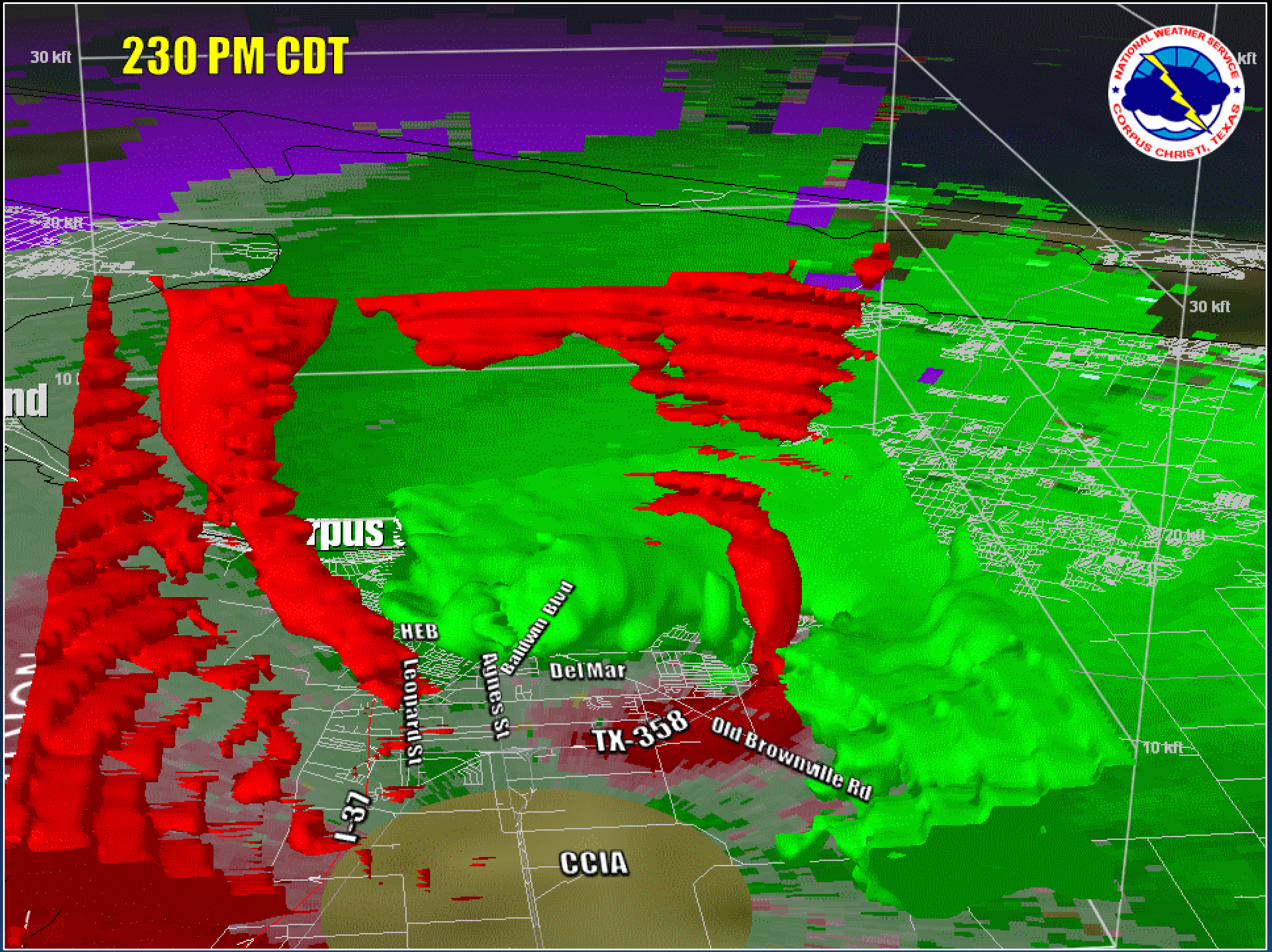


Tornado

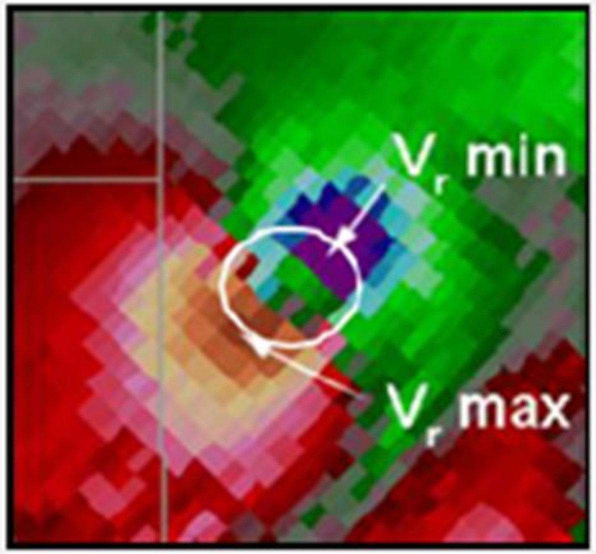
Tornado Indicators

- TVS/TS
- TDS
- Hook Echo/BWER
- QLCS Mesovortices
- Bookend Vortices
- Tropical Cyclone Tornadoes

Corpus Christi EF-2 Tornado on October 24, 2002



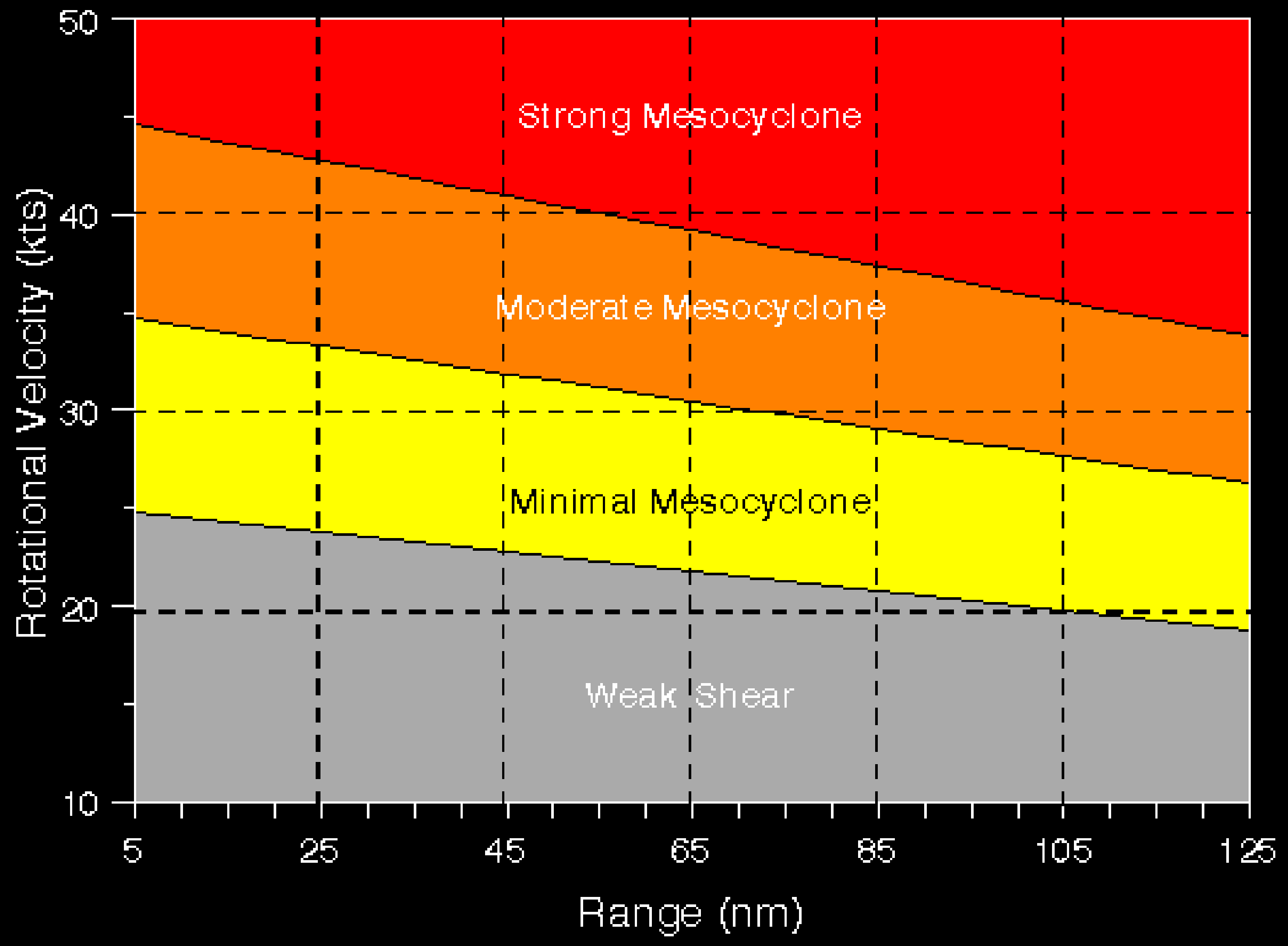
Low Level Rotational Velocity (LLRV)



$$V_{rot} = (|V_{in[max]}| + |V_{out[max]}|) / 2$$

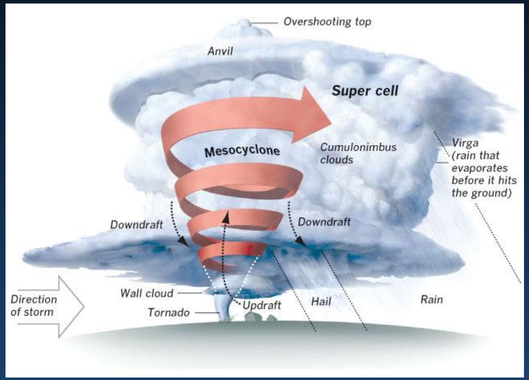
To determine rotational velocity, add the absolute value of the highest inbound and outbound velocity values in the couplet, and then divide by 2.

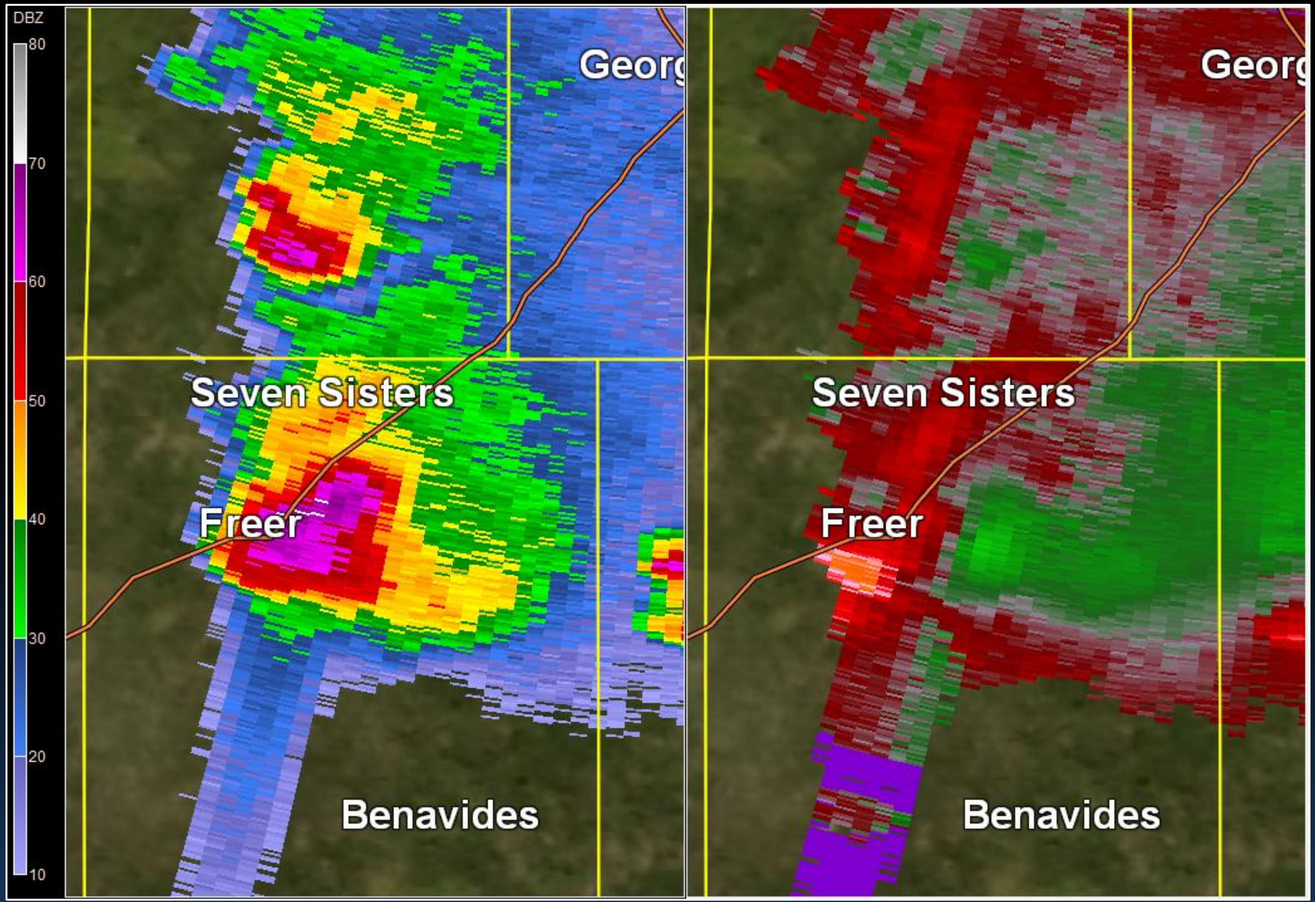
Mesocyclone Recognition Guidelines



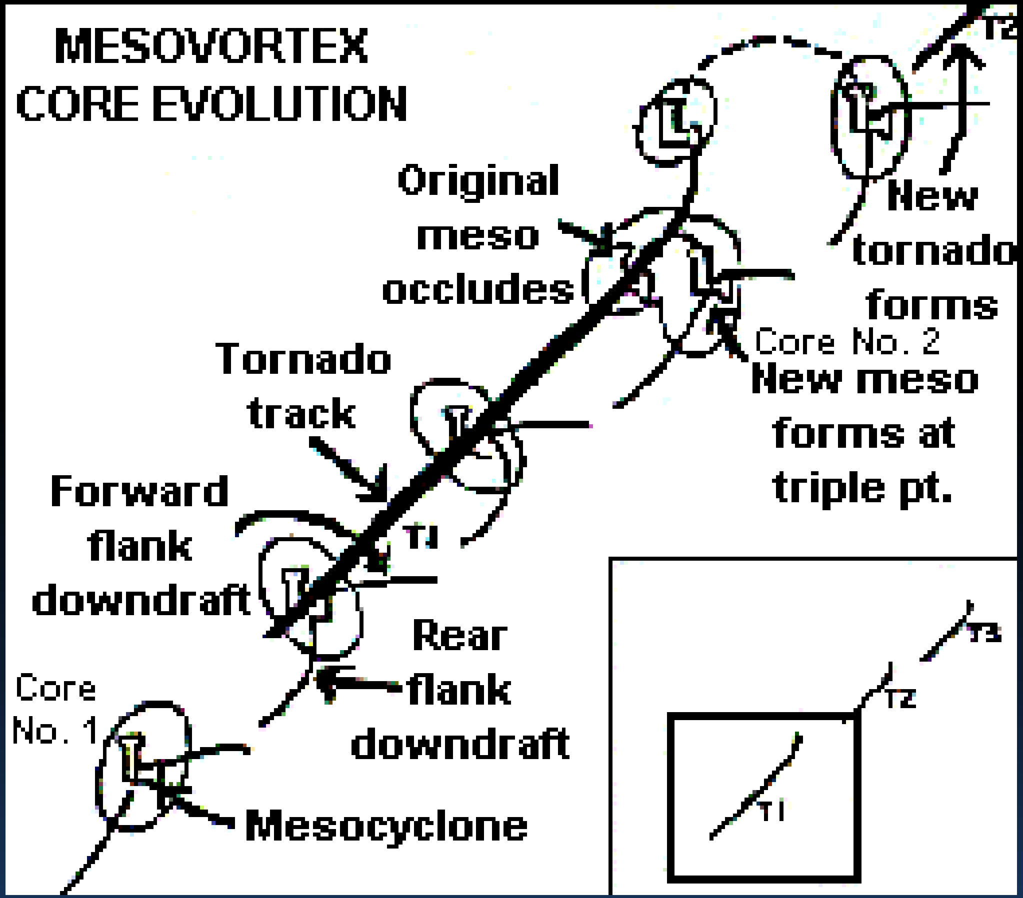
Mesocyclone Criteria

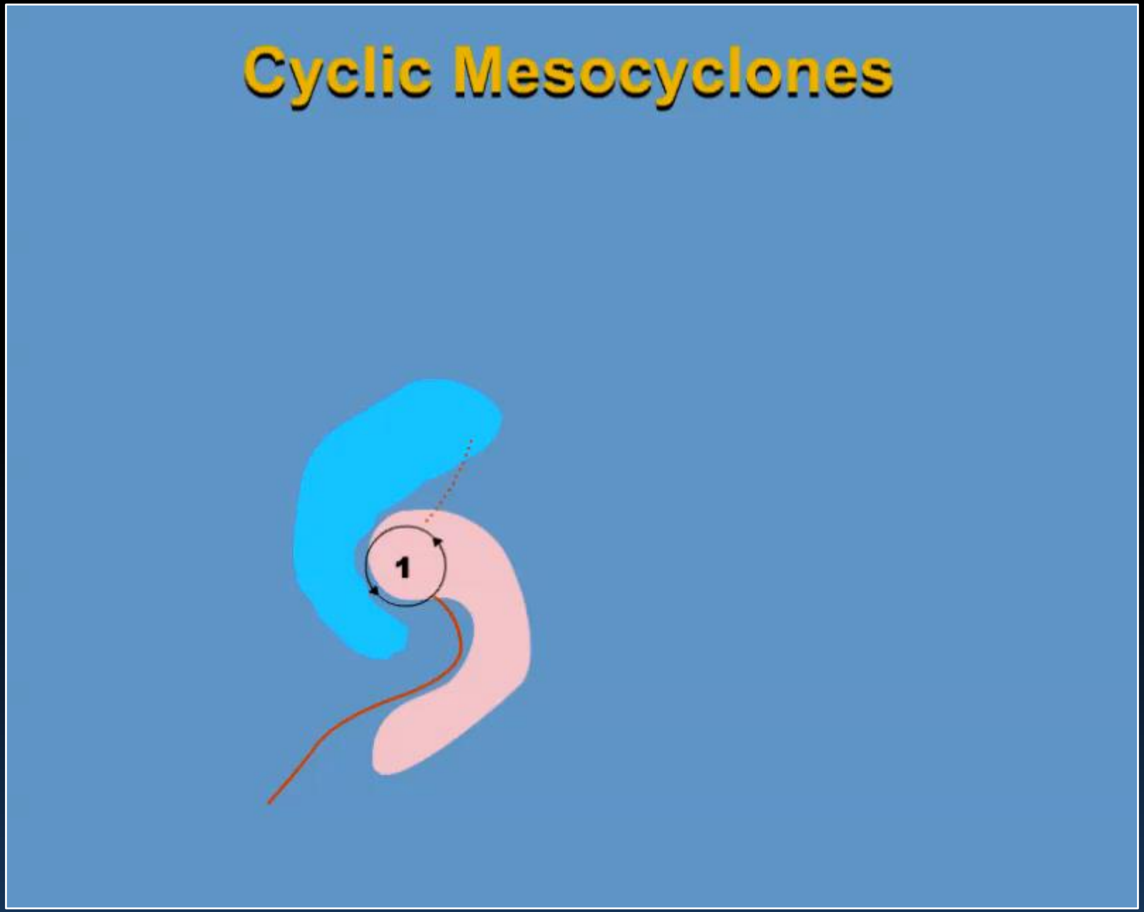
- Core diameter typically < 5 nm.
- LLRV exceeds minimal mesocyclone strength.
- Persistence > 10 min.



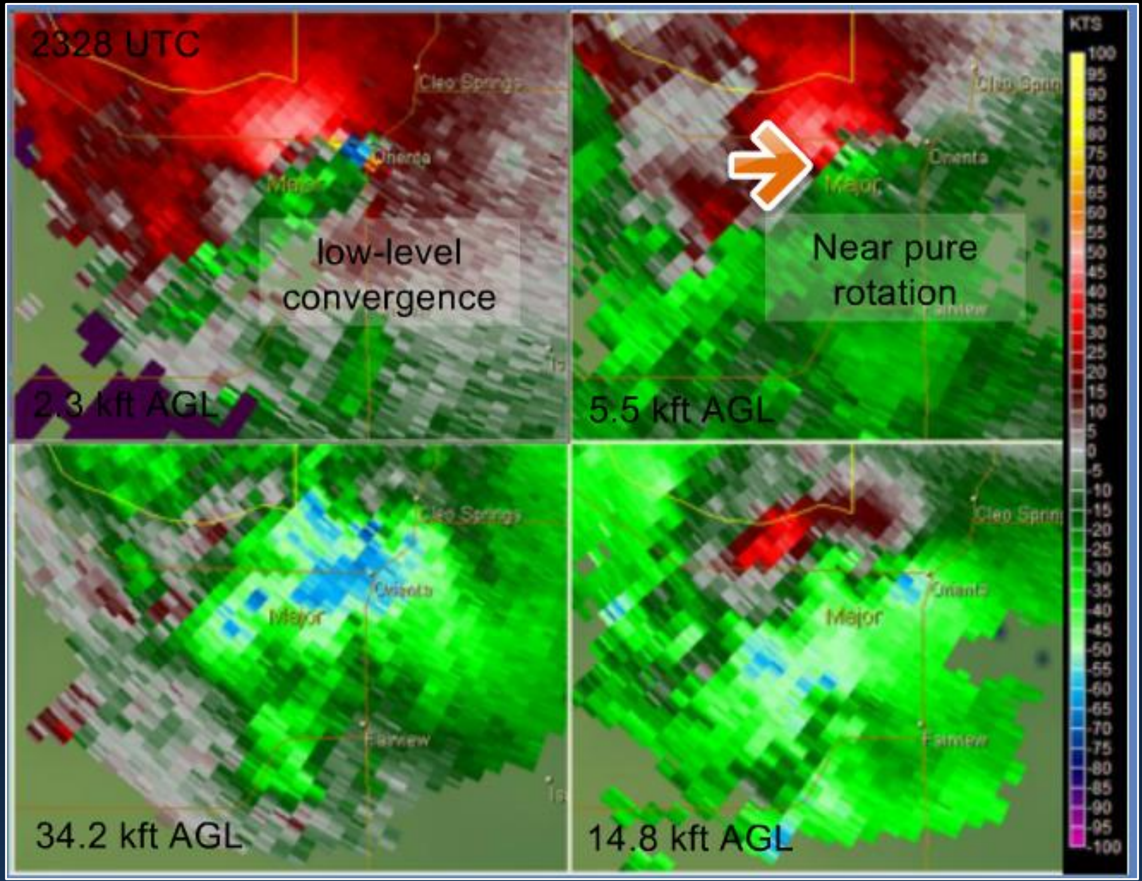


Mesocyclone Evolution



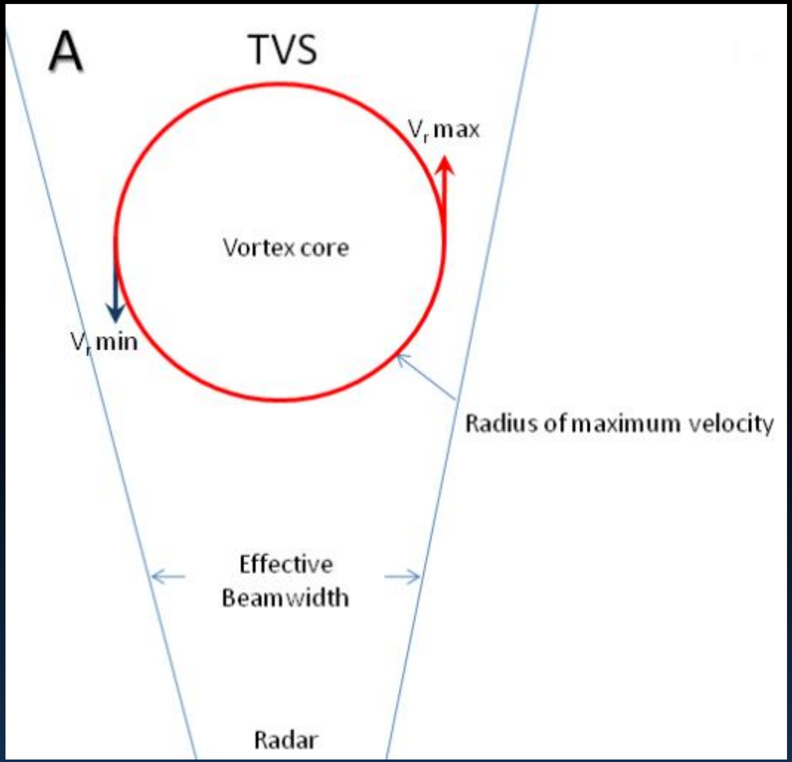


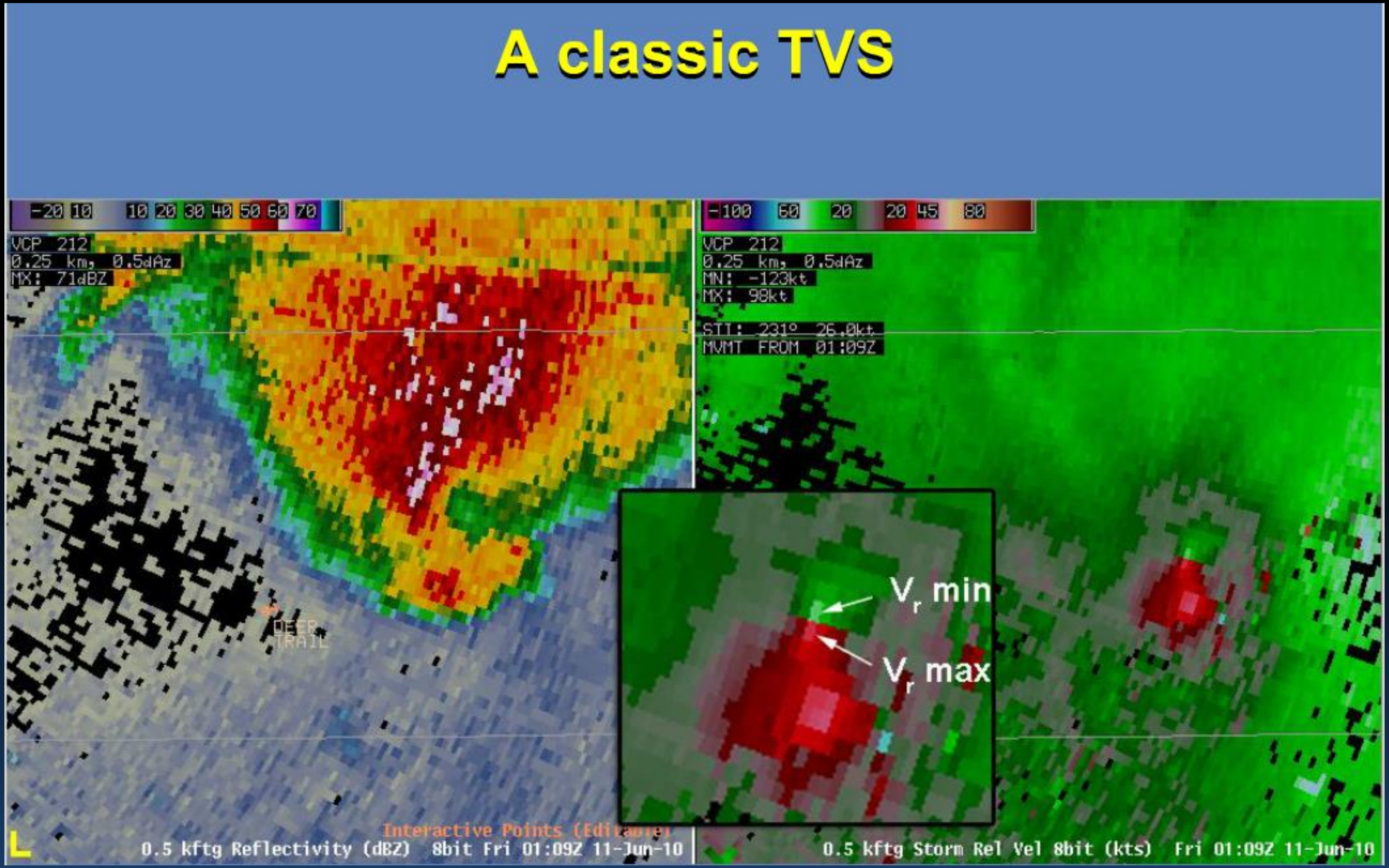
Mesocyclone Lifecycle



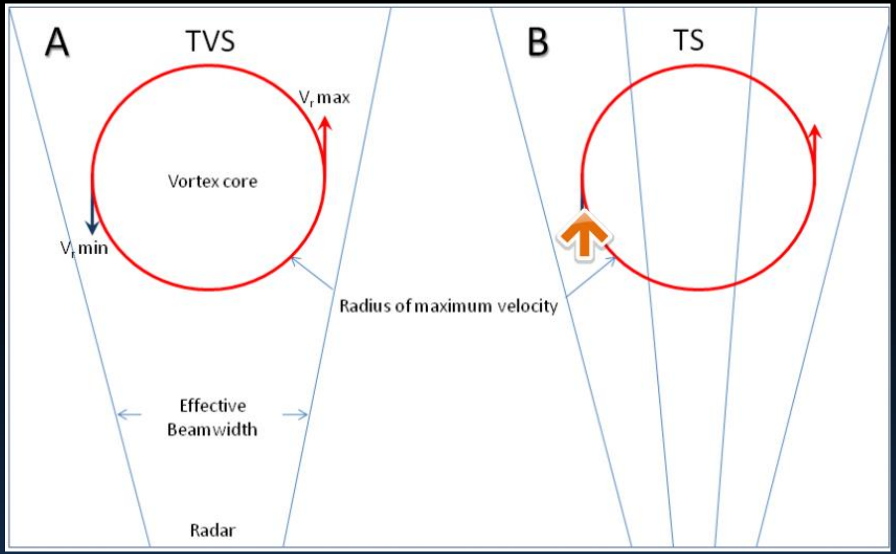
- Starts in mid levels.
- At Mature Stage:
  - Low-level convergence
  - Mid-level pure rotation
  - Upper-level divergence

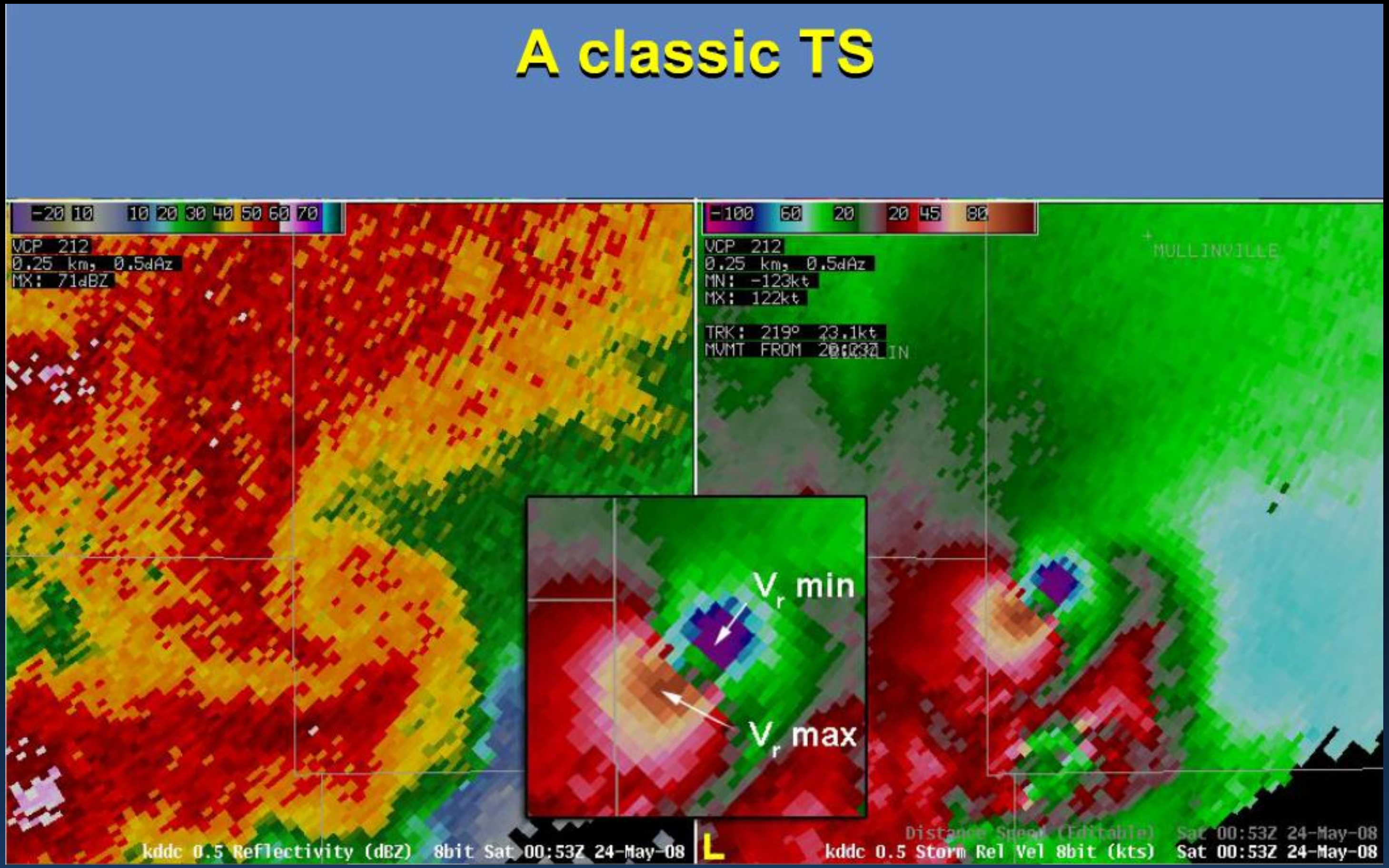
Tornadic Vortex Signature (TVS)





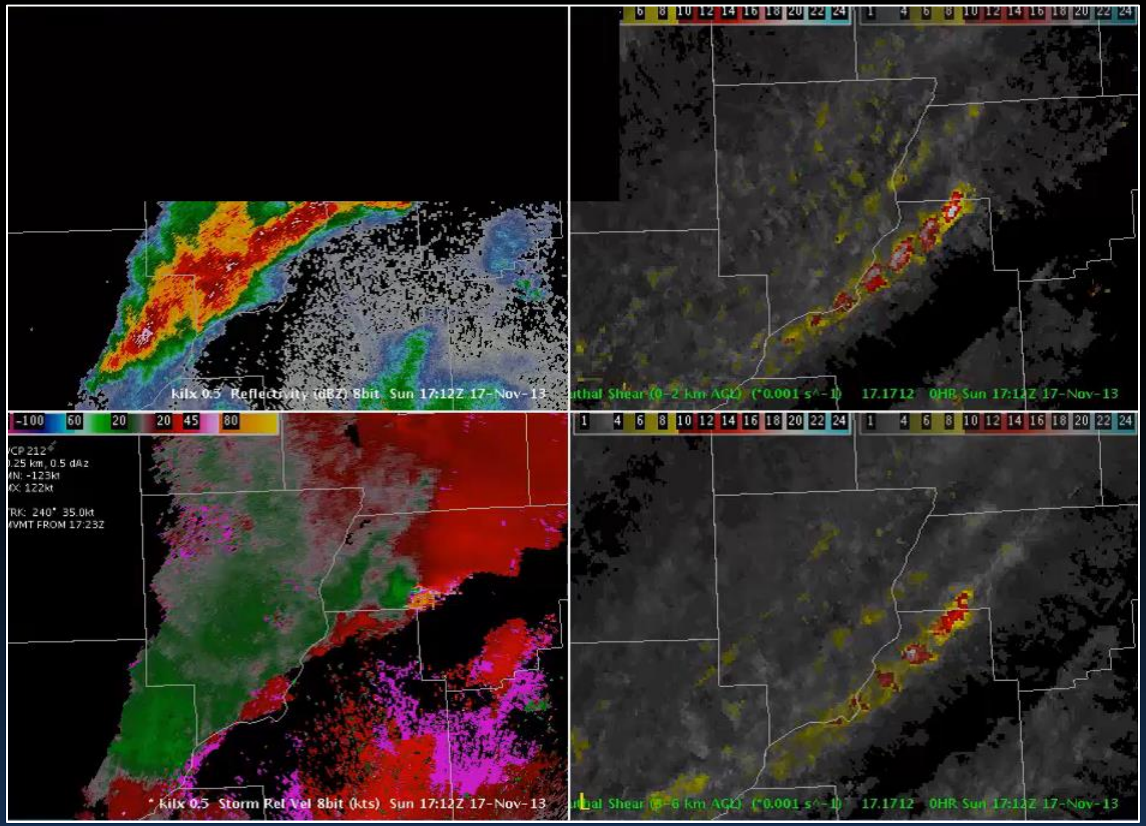
Tornado Signature (TS)





MRMS Rotation Tracks (0-2km, 3-6km AGL)

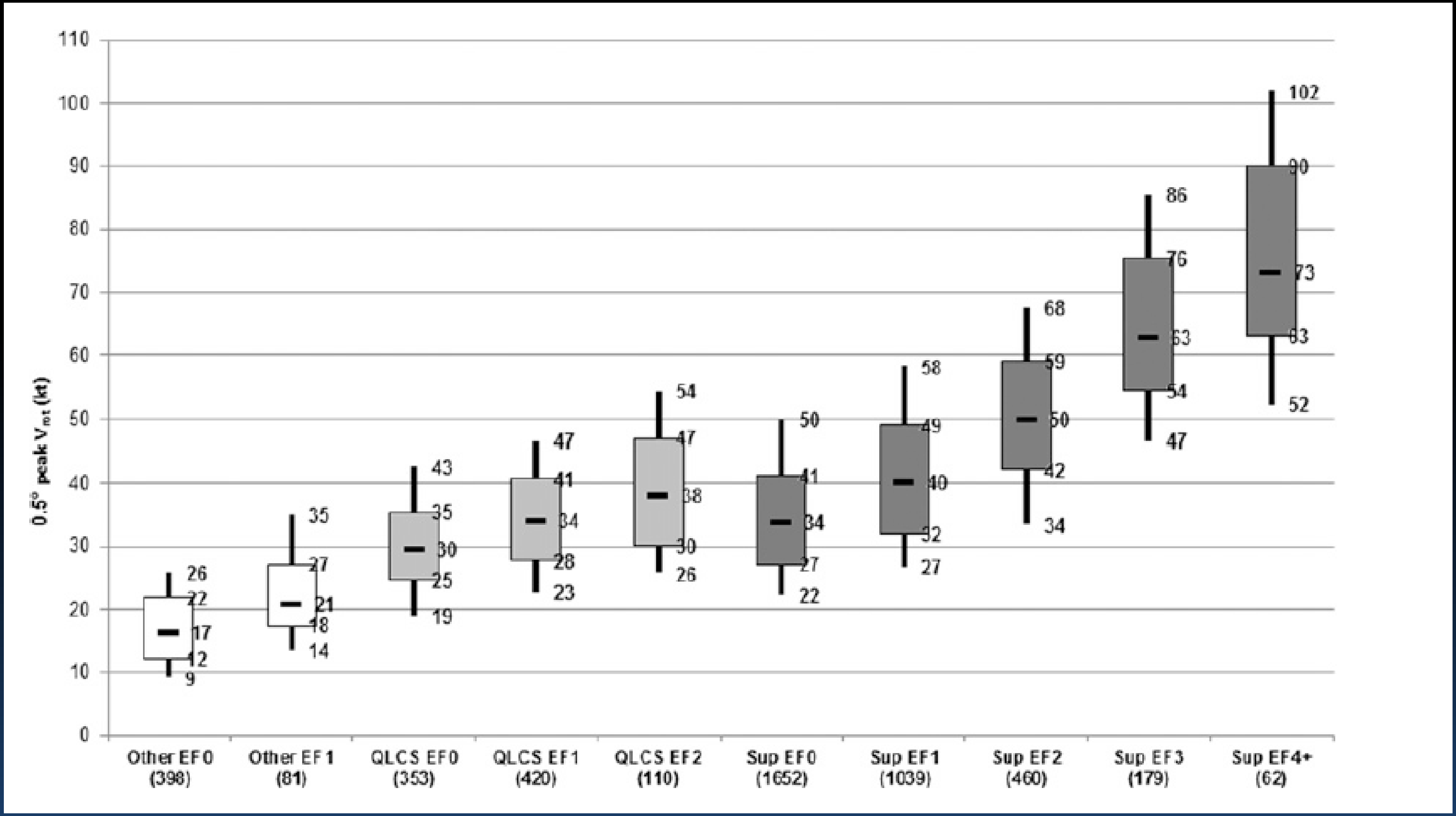
- Azimuthal Shear
- Intensity and Coverage Trends
- Great for detecting supercells.
- Detect smaller-scale circulations such as mesovortices.
- Great for damage surveys.



Tornado Impact-Based Warnings (IBW)

Peak 0.5° LLRV vs. EF-Scale

for ≤ 10k ft within 101 mile radius



Smith et. al. 2015

Impact Based Warnings Guidance

30 KT V_{rot}
Initial Supercell Tornado Warning Threshold

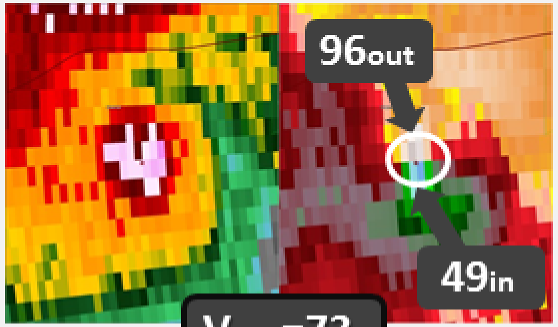
40 KT V_{rot}
Considerable Tag Threshold With TDS

50 KT V_{rot}
Considerable Tag Threshold Without TDS

* These are guideline thresholds. Should be used in context with other IBW resources found at: http://training.weather.gov/wdtd/courses/ibw/references.php

Measuring V_{rot}

$$V_{rot} = \frac{(|V_{in[max]}| + |V_{out[max]}|)}{2}$$



Is velocity in area of >20 dBZ signal?

Nowcasting Significant Tornadoes

TDS Height Threshold
EF2+: 8,000-10,000 ft.

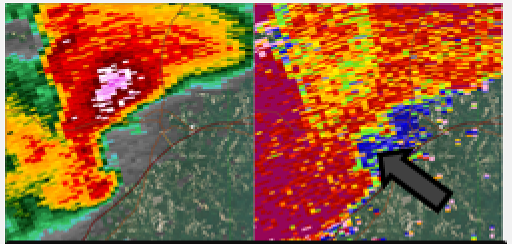
Other EF-2+ Indicators:

- 8,000 ft. or deeper mesocyclone with $V_{rot} \geq 30$ kt persisted for 2 volume scans
- Peak $V_{rot} \geq 50$kt on any elevation angle in last 3 scans
- 0.5 Near Gate-to-Gate ≥ 70 kt on any of the last 3 scans
- Near Storm Environment (NSE)
- Past History of Storms

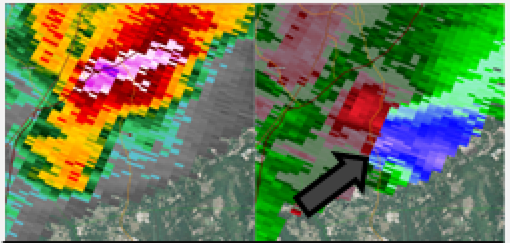
Upgrade to Catastrophic Tag
"Tornado Emergency" if:
(Must meet ALL)

1. Tornado Confirmed (TDS or credible source)
2. Expected to impact populated area
3. Believed to be strong/violent (EF-2+)

Potential Pitfalls



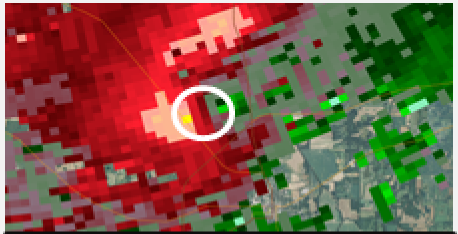
CAUTION: Low CC in inflow area can APPEAR to be TDS
Make sure the dBZ is ≥20



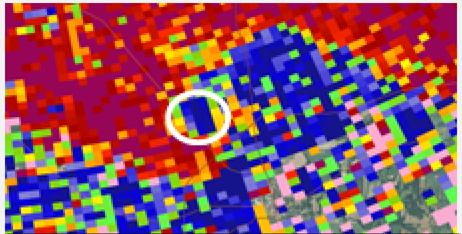
Vertical Side Lobe Contamination
Strong velocity in Weak Z below strong meso aloft, may not be valid signal

Tornado Debris Signature (TDS) Identification

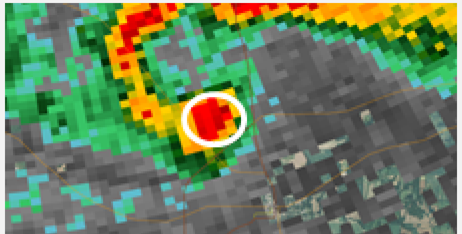
Criteria for a "Radar Confirmed Tornado"



First, Identify a valid velocity circulation



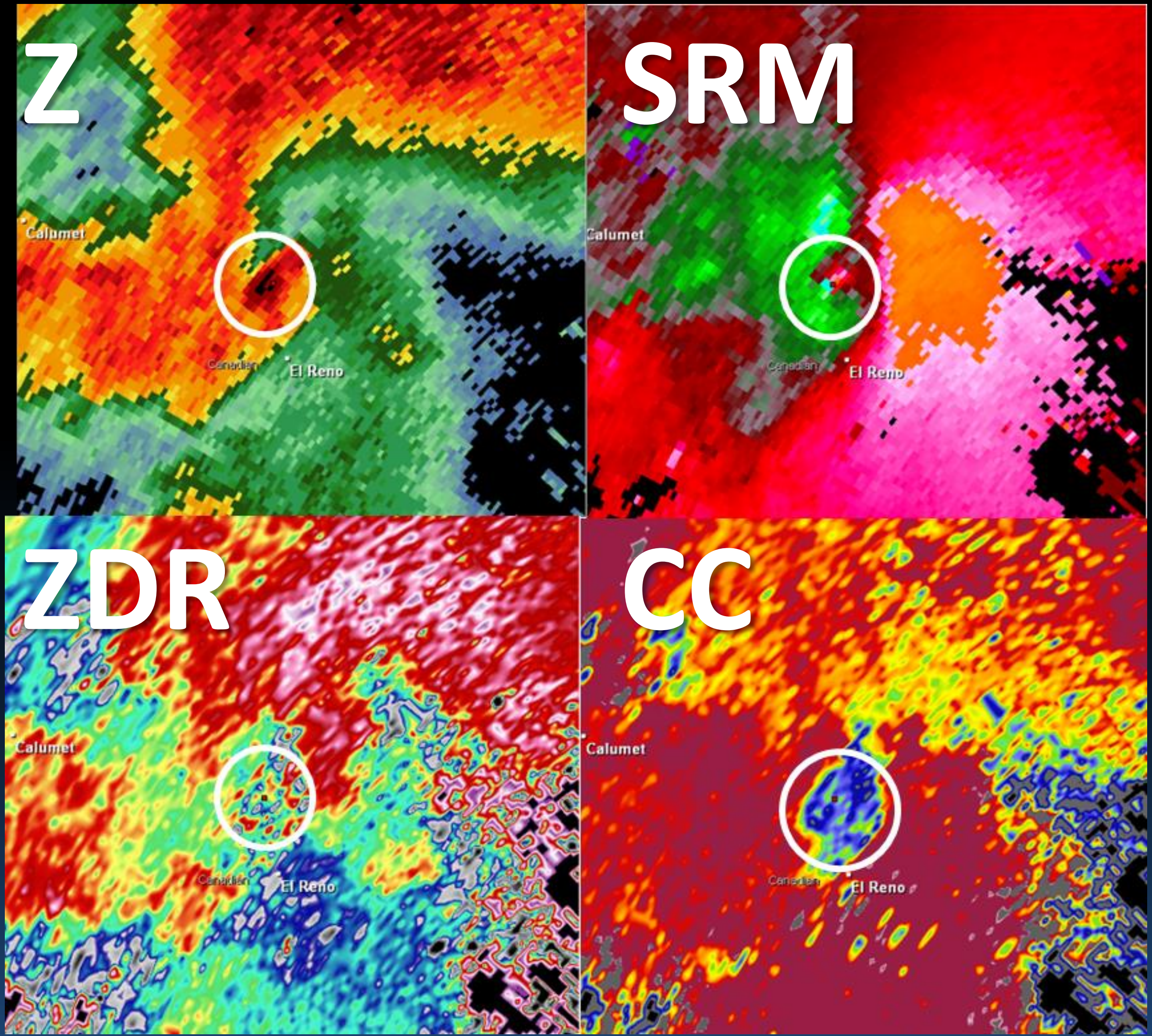
Is the CC below 0.90?



Collocated Z above 20 dBZ?

ZDR near zero? – Not necessary but adds confidence

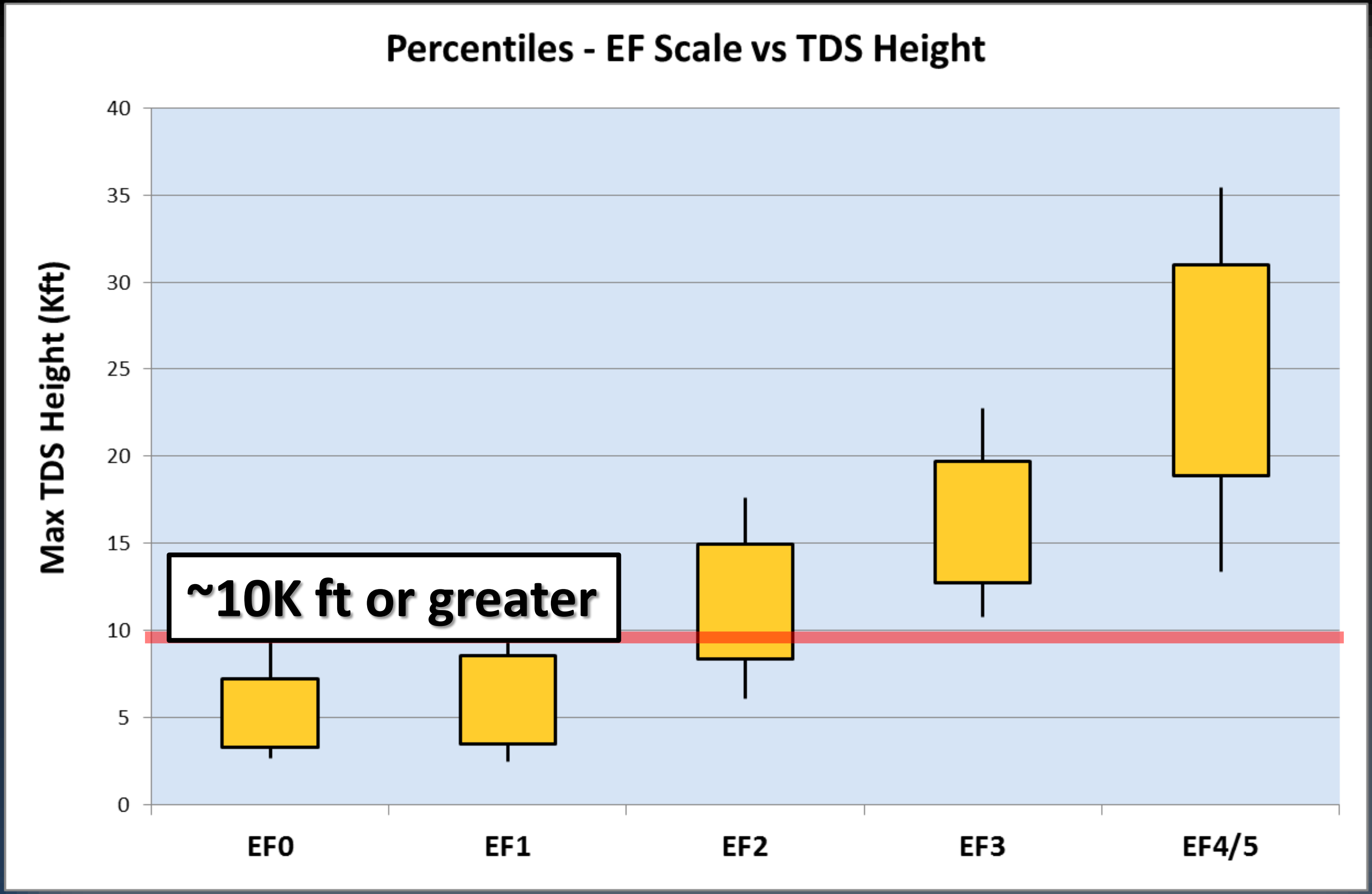
Tornadic Debris Signature (TDS)



- Identify a valid velocity circulation.
- CC < 0.90 collocated with the circulation.
- Sufficient reflectivity > 35 dbZ collocated.
- ZDR near 0 or below.

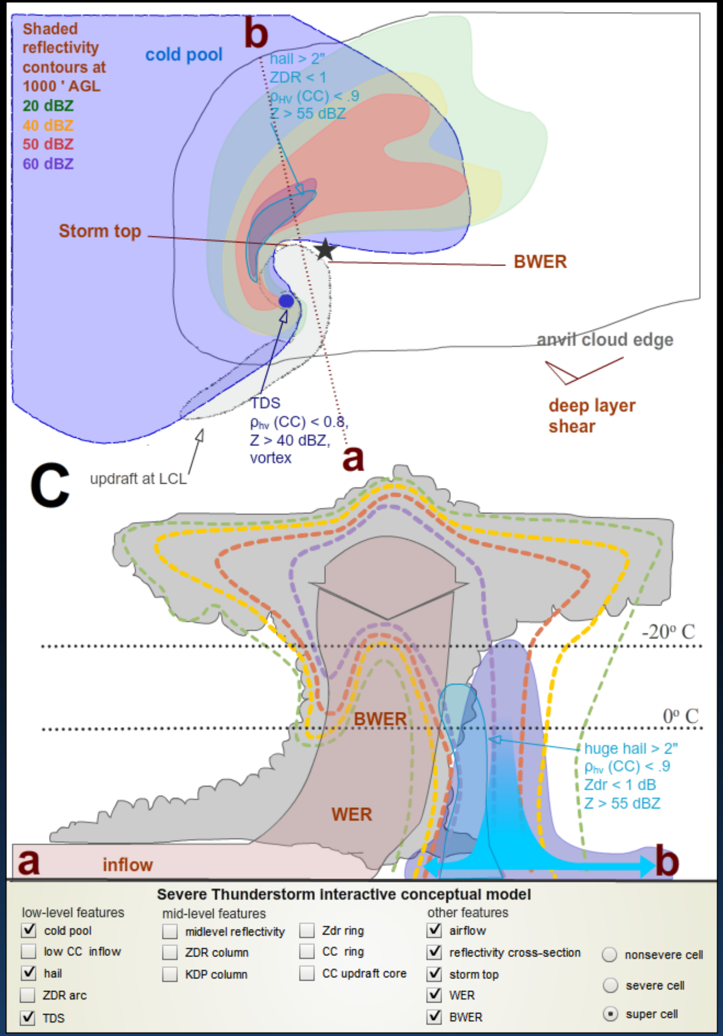
Entremont et. al.

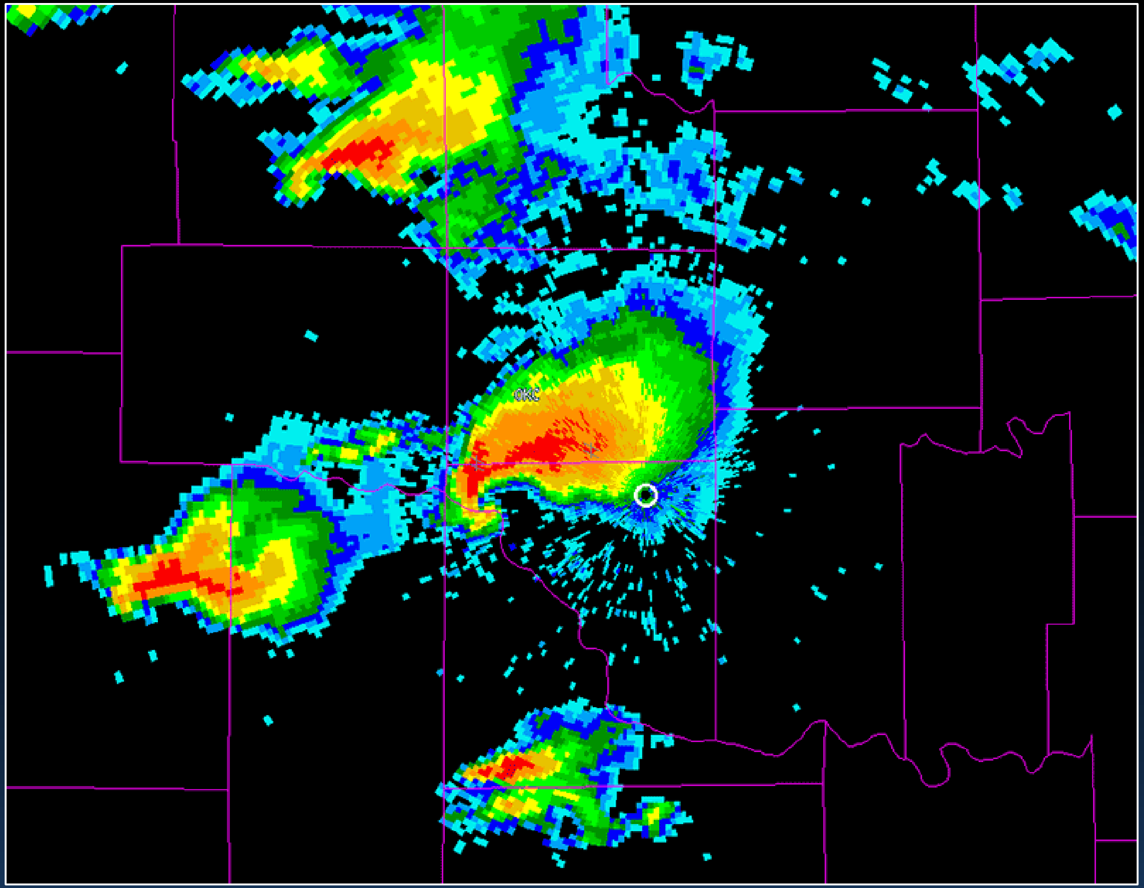
TDS Height vs. Tornado Intensity

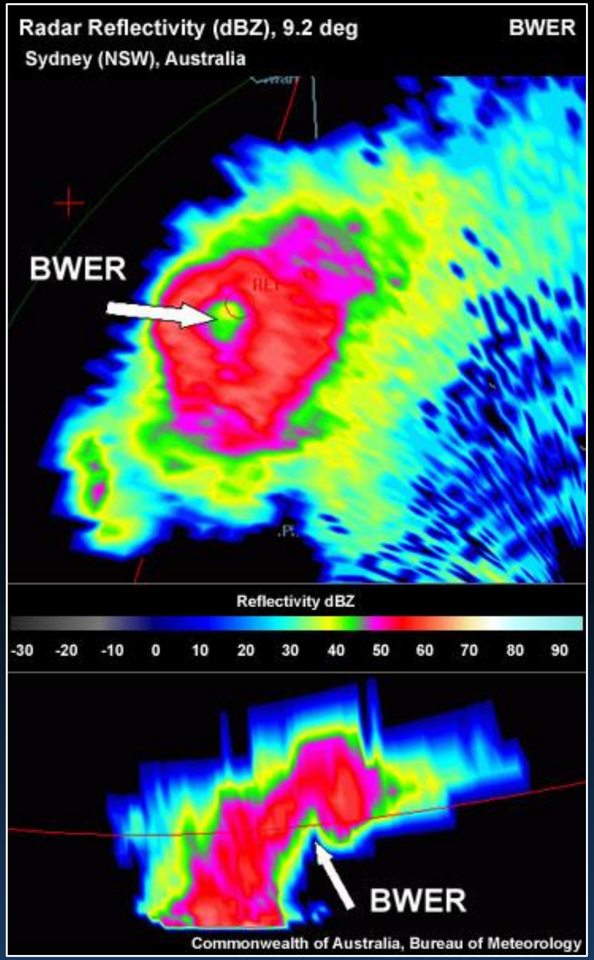


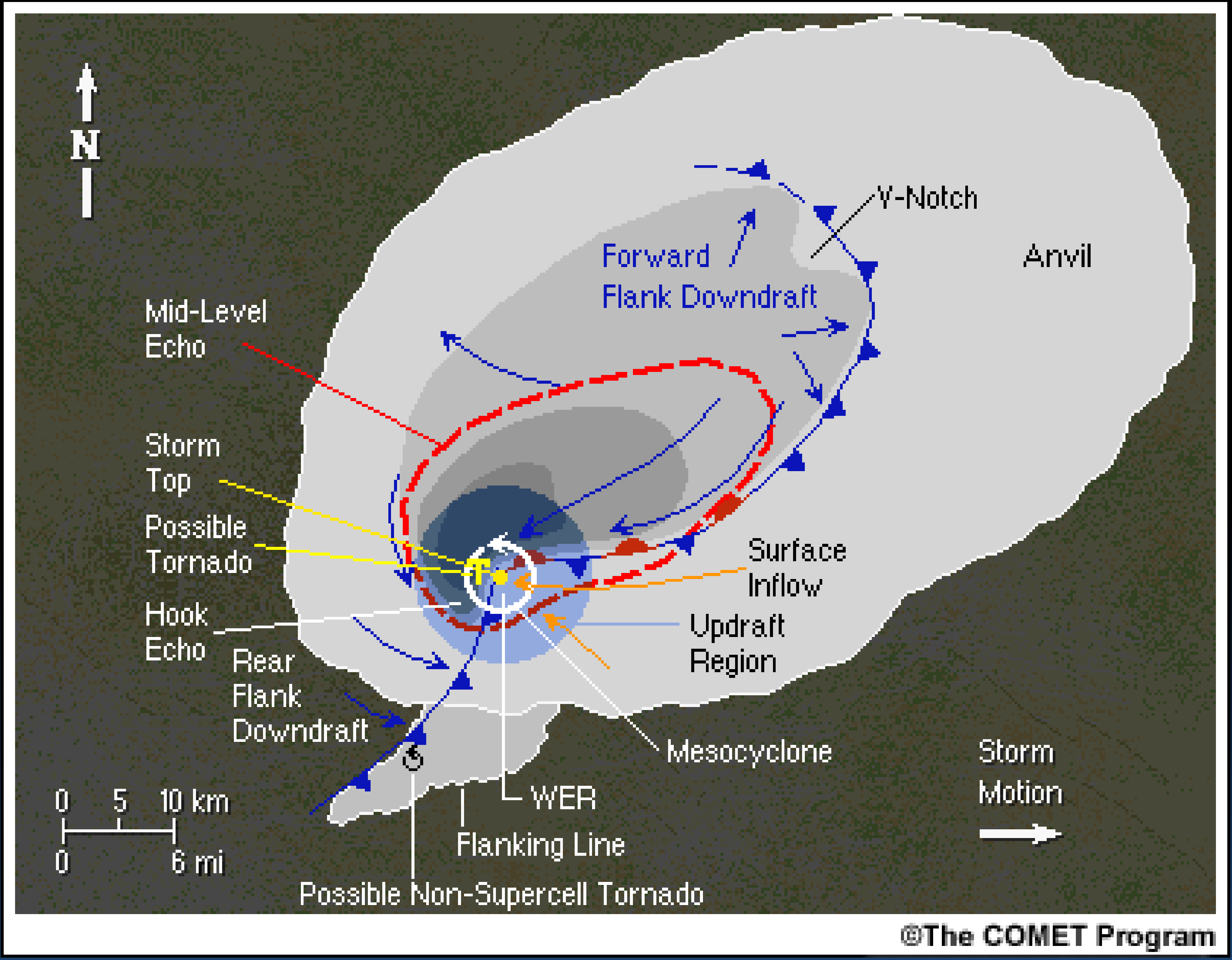
Entremont et. al.

Lemon Technique for Tornado Warning:
BWER and Hook Echo





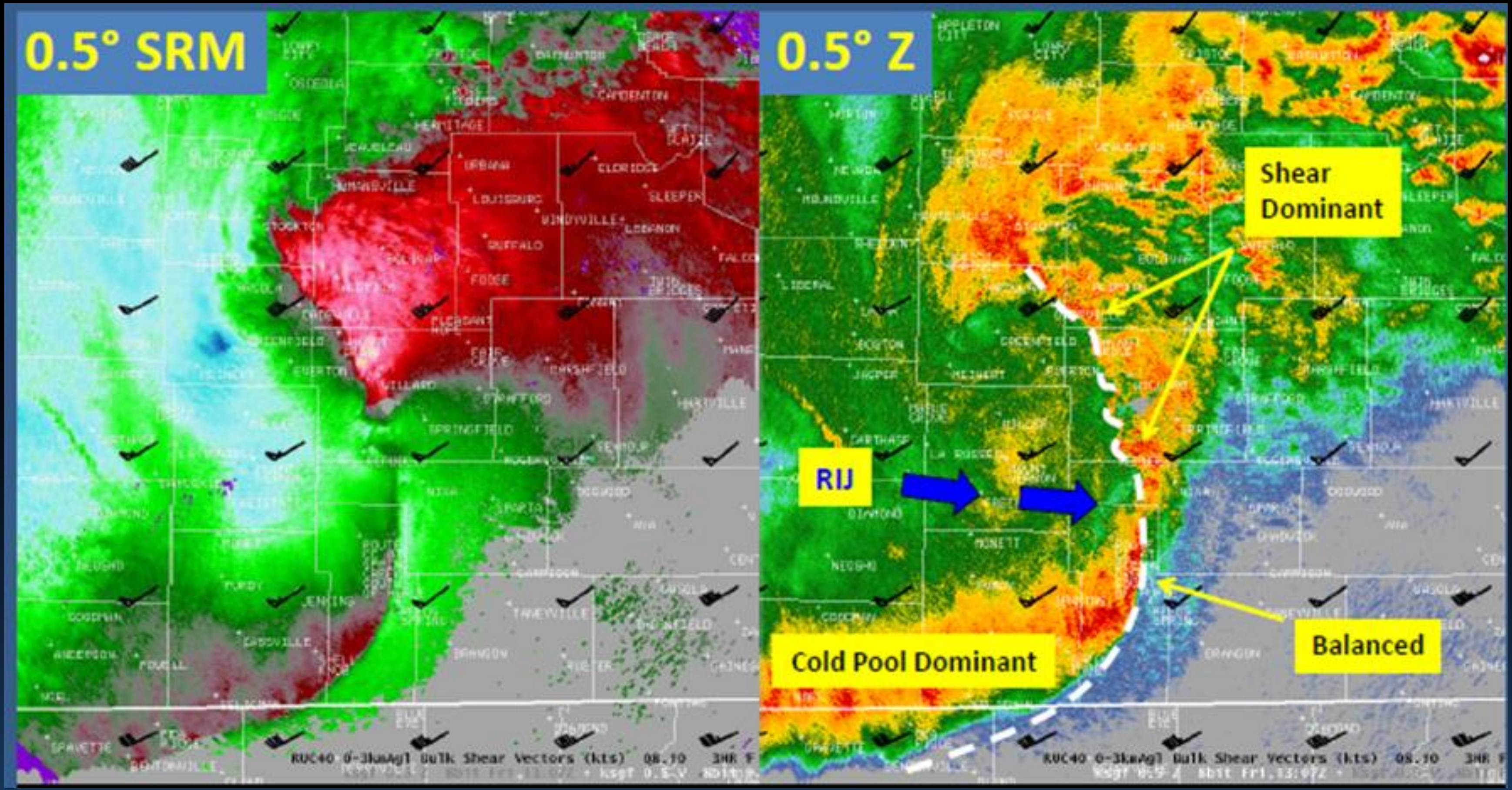



N
Y-Notch
Anvil
Forward
Flank Downdraft
Mid-Level
Echo
Storm
Top
Possible
Tornado
Hook
Echo
Rear
Flank
Downdraft
Surface
Inflow
Updraft
Region
Mesocyclone
WER
Flanking Line
Possible Non-Supercell Tornado
Storm
Motion
0 5 10 km
0 6 mi
©The COMET Program

QLCS Mesovortex Tornadoes and the 3 Ingredients Method

1.) Locate the Balanced or Slightly Shear Dominant section of the QLCS.

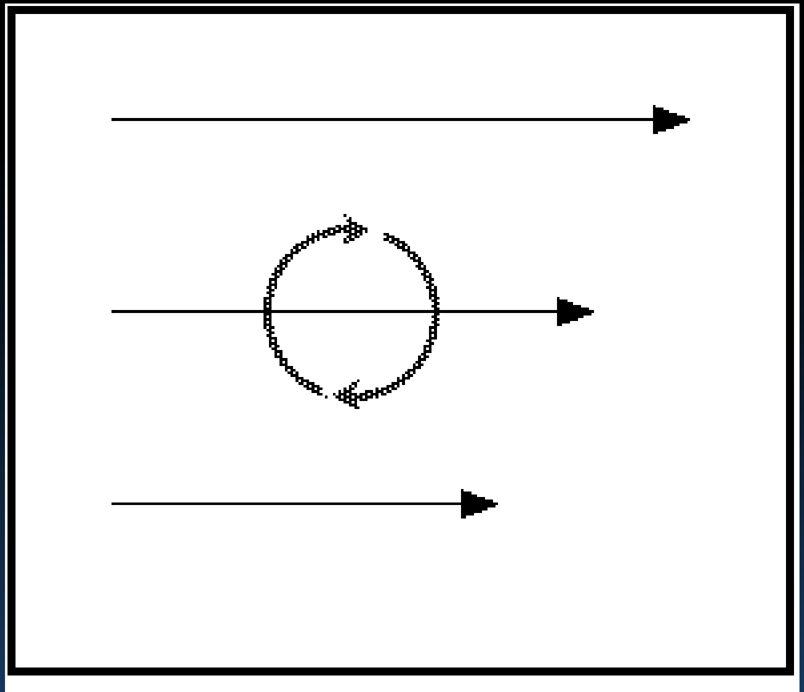
- Define the Updraft Downdraft Convergence Zone (UDCZ)
  - Coincident with gust front.



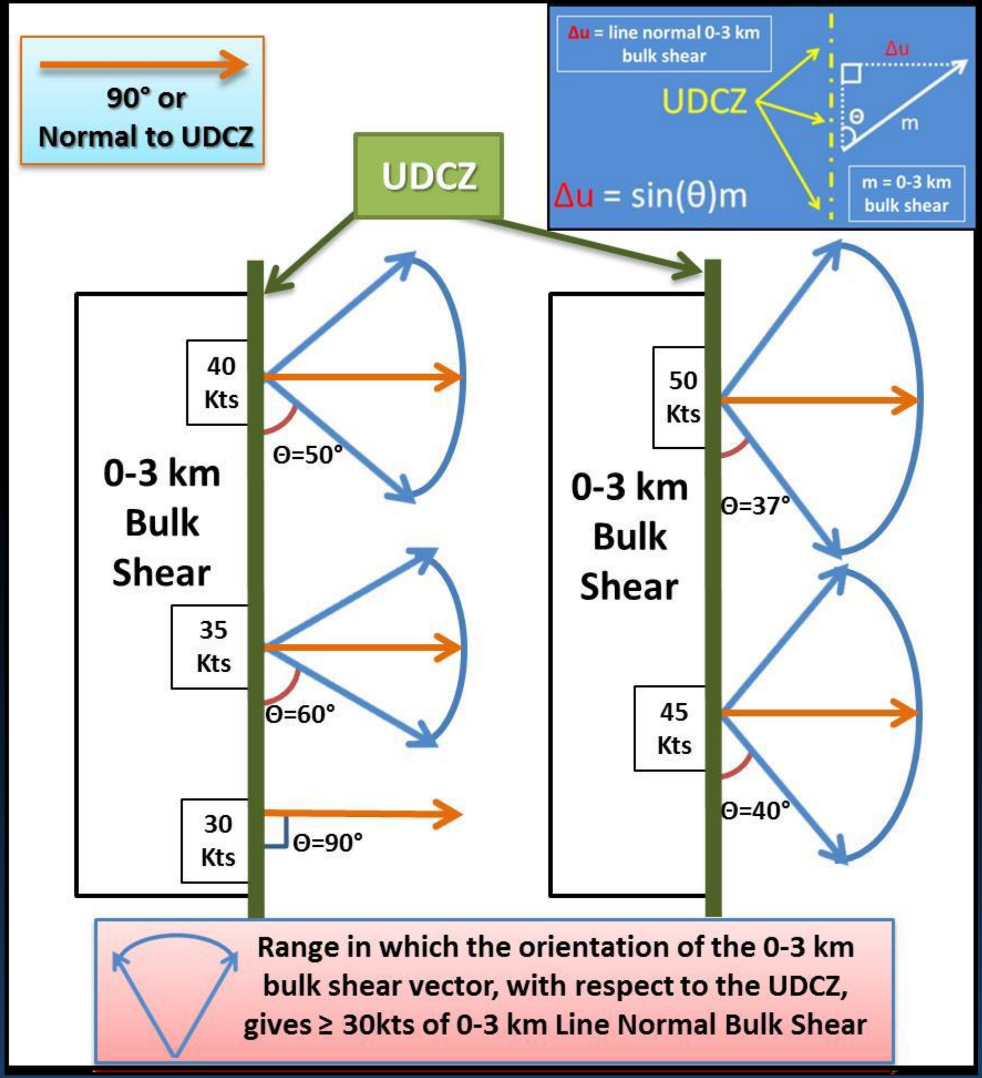
Schaumann and Przybylinski 2012

2.) Find Line-Normal 0-3 km Bulk Shear ≥ 30 kts

- Important in the creation of horizontal shear vorticity.

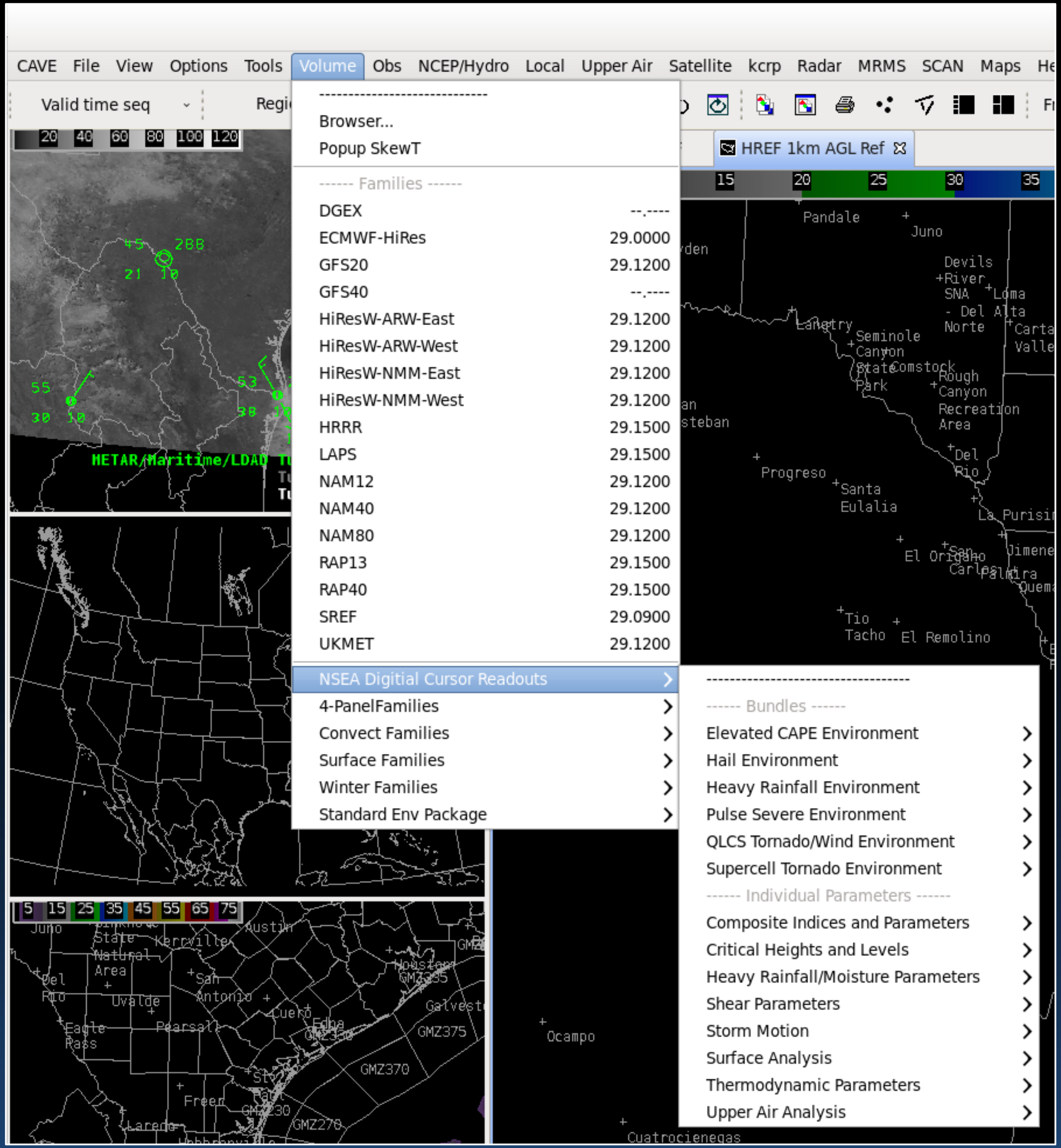


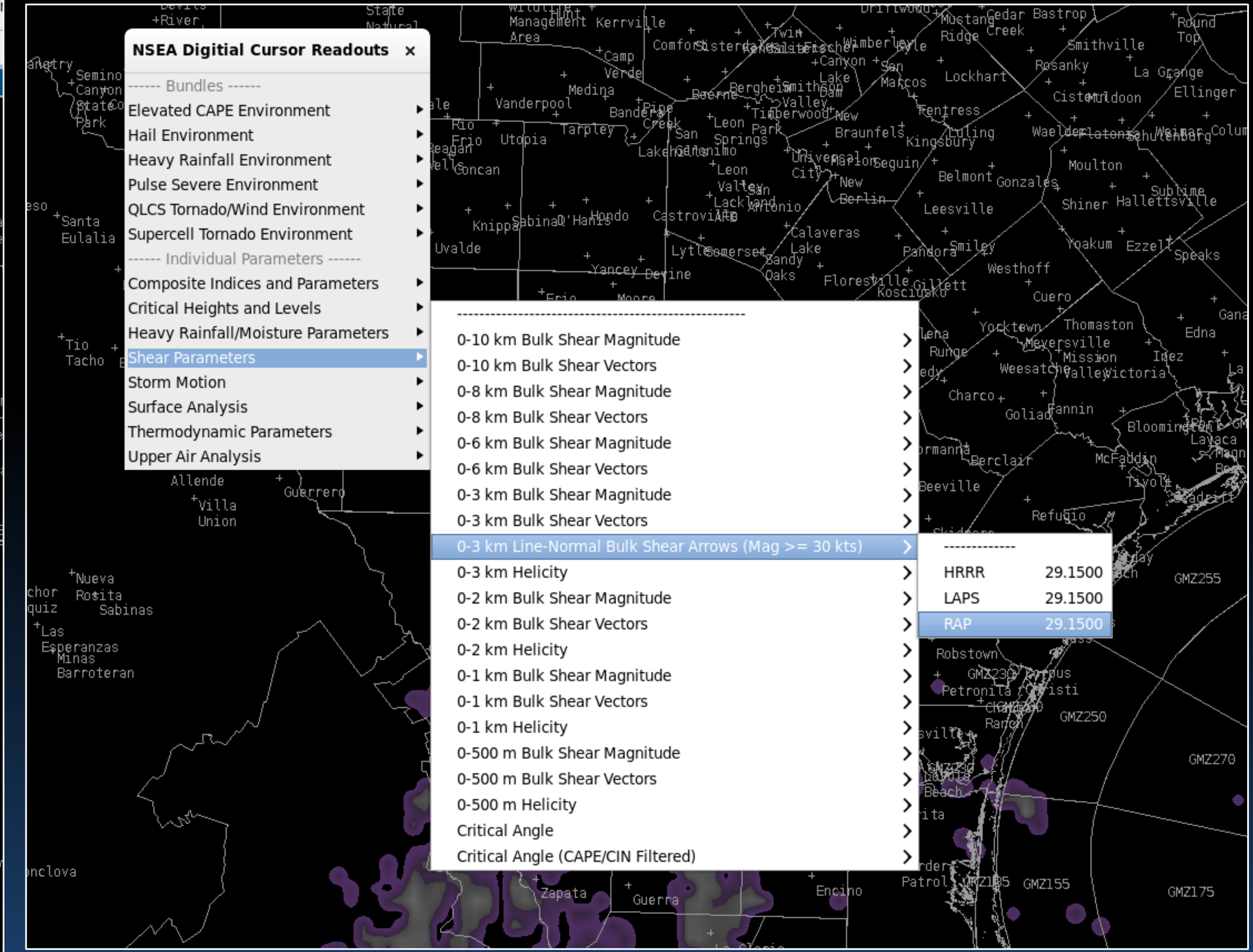
Shear Vorticity



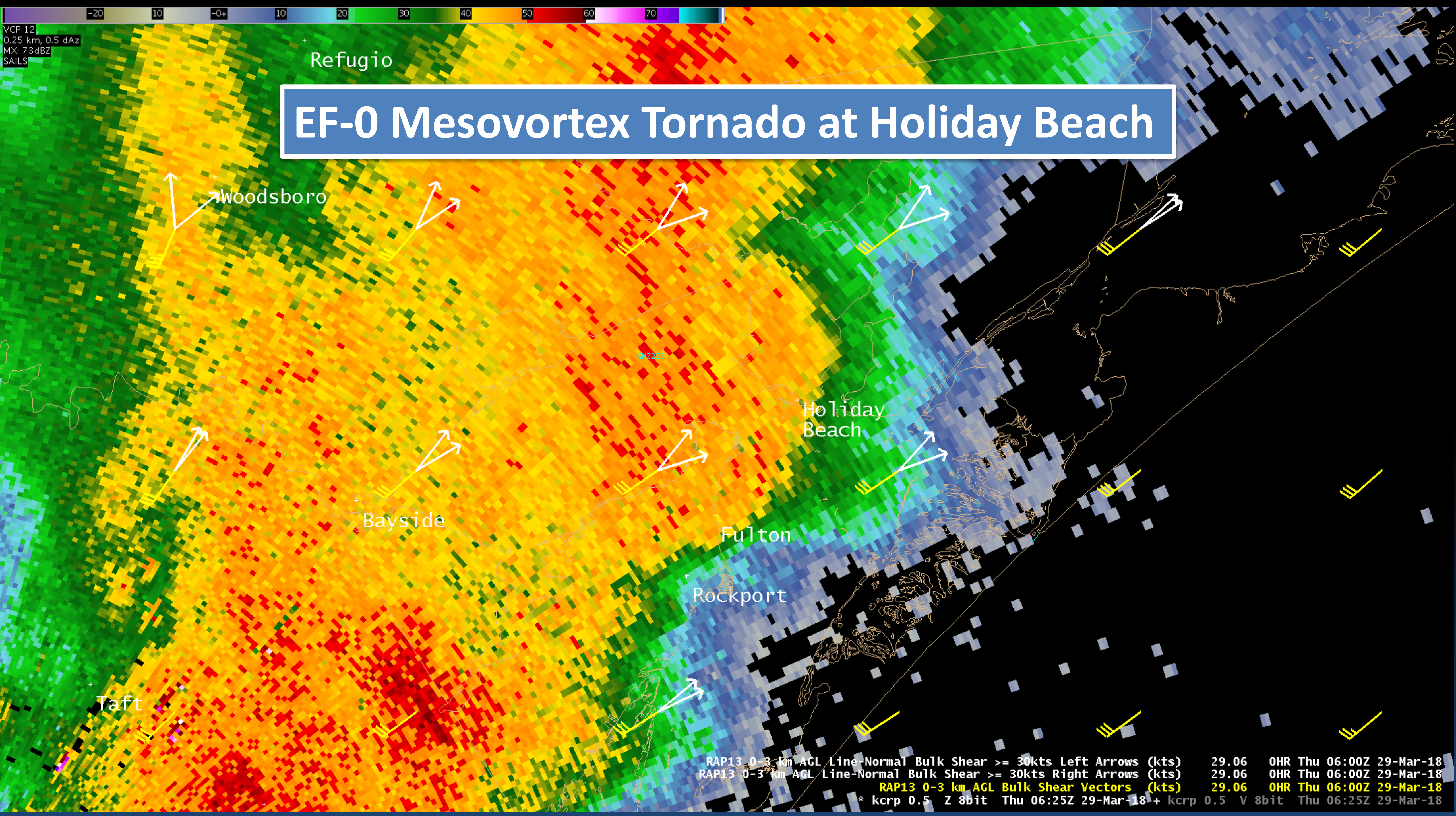
Schaumann and Przybylinski 2012

NSEA Digital Cursor Readouts Tool

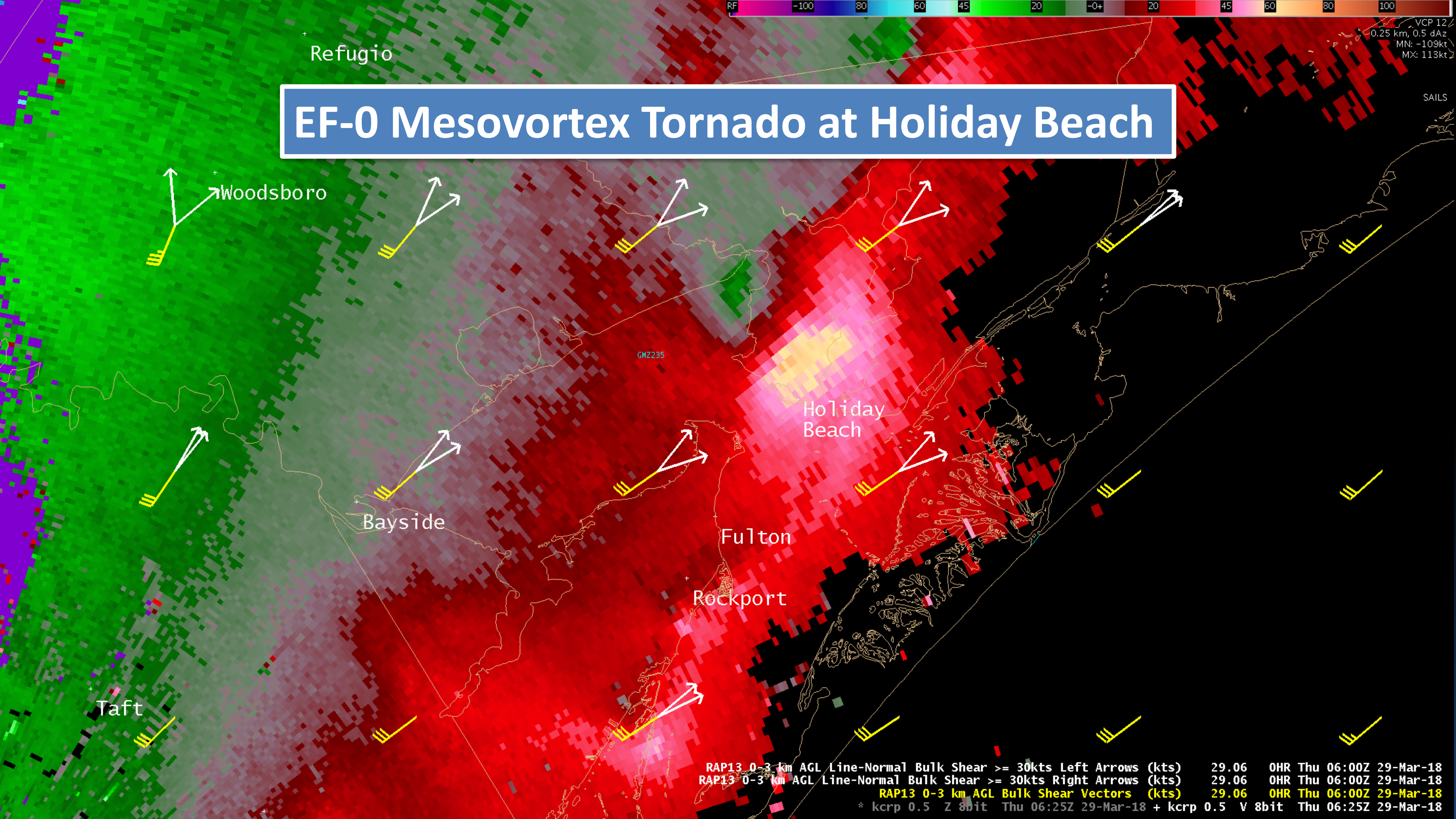




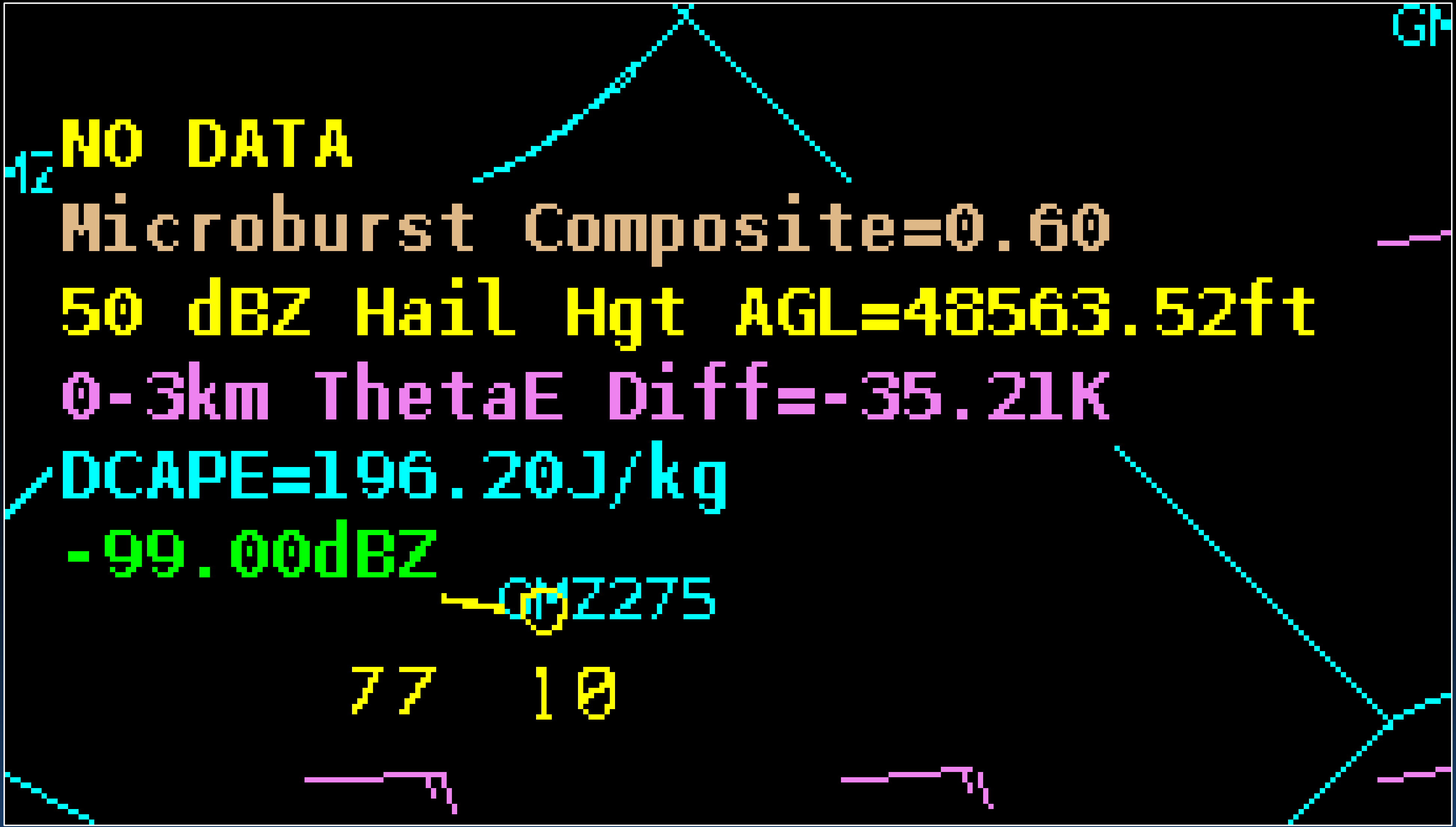
EF-0 Mesovortex Tornado at Holiday Beach



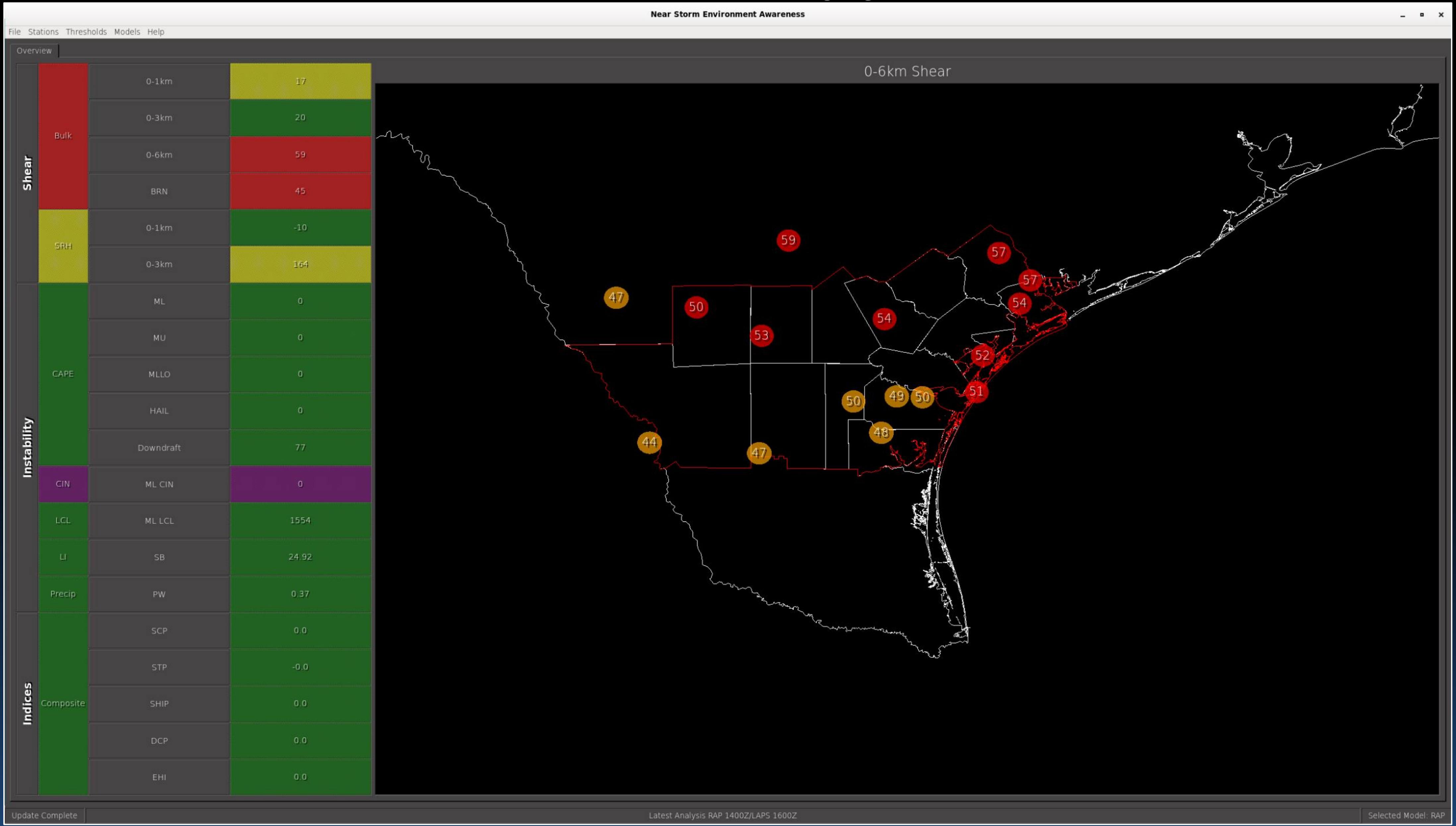
EF-0 Mesovortex Tornado at Holiday Beach



NSEA

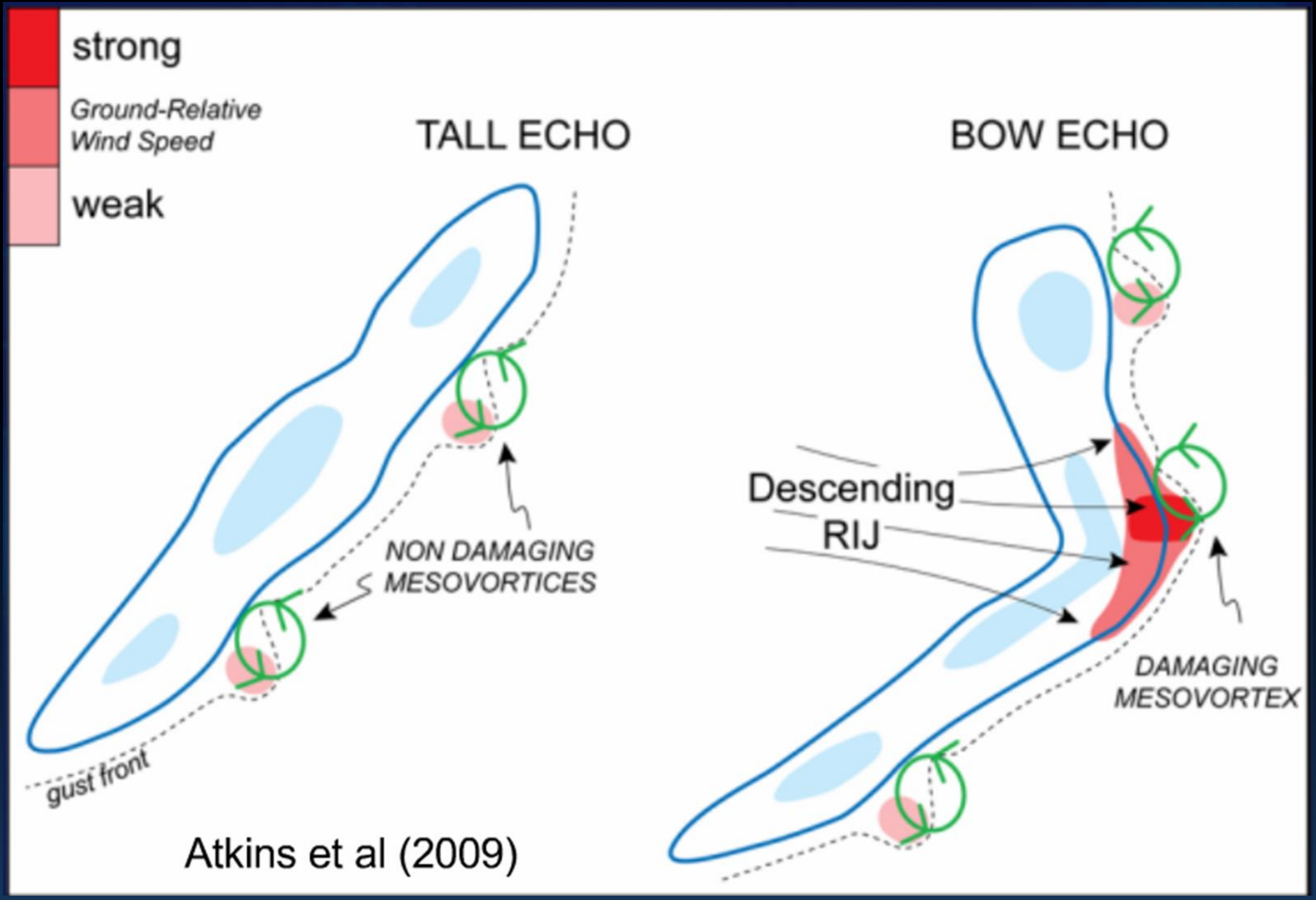

NO DATA
Microburst Composite=0.60
50 dBZ Hail Hgt AGL=48563.52ft
0-3km ThetaE Diff=-35.21K
DCAPE=196.20J/kg
-99.00dBZ
77 10

NSEA Local AWIPS App (RAP/LAPS)



3.) Look for Surges or Bows in the Line

- A RIJ or enhanced outflow are likely candidates to cause a surge or bowing.
- Use both SRM and V.
- **When all 3 items are co-located, there is an increased likelihood of tornado-producing mesovortices.**



Schaumann and Przybylinski 2012

1. Enhanced Surge

- Tip of local surge is displaced more than 5 nm from rest of line OR larger bow is accelerating.

2. Inflection Point

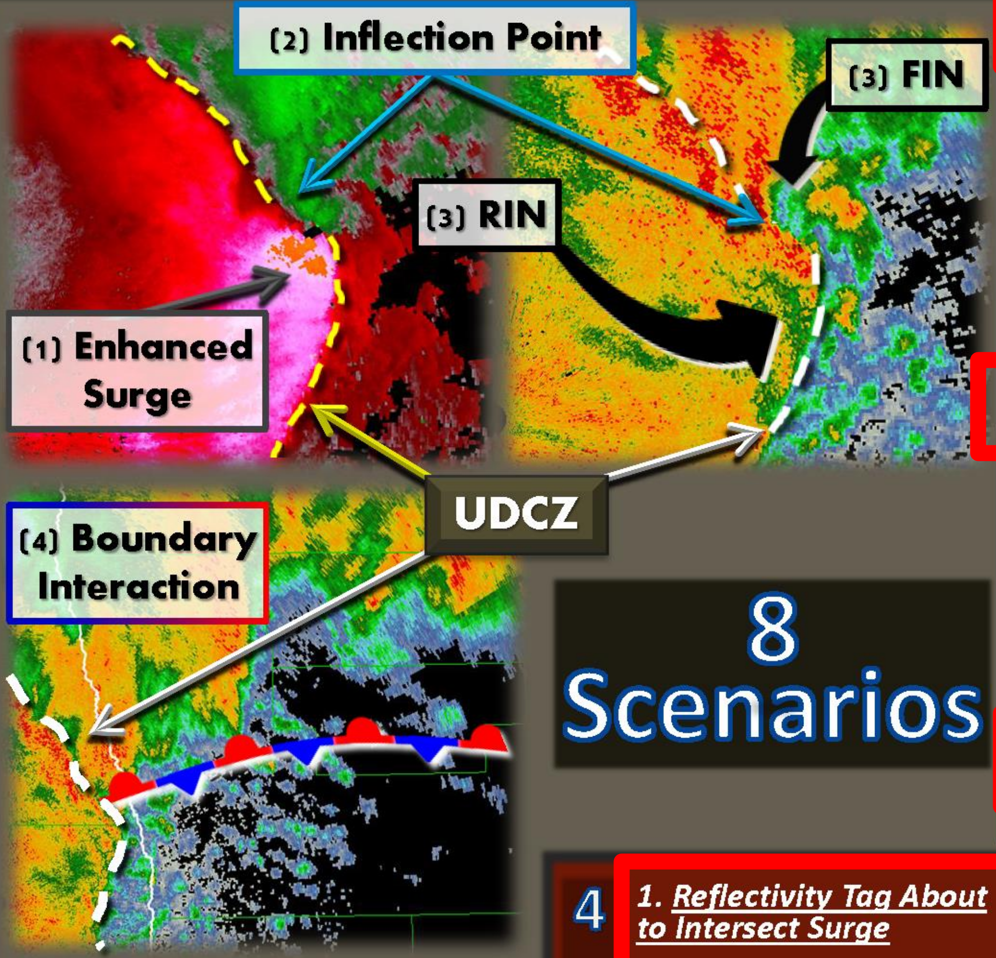
- Located where the UDCZ curls from the leading edge back into the precipitation.

3. Paired Front & Rear Inflow Notch (FIN/RIN)

- FIN on front & often northern side of surge. RIN location is typically directly behind FIN, but depends on trajectory of the RIJ/outflow.

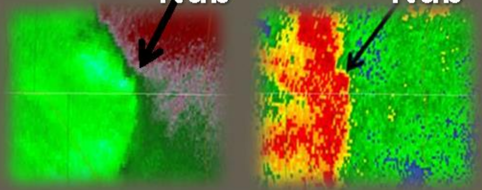
4. Boundary Interaction

- Synoptic front or convective outflow ingested by surge. Front is typically stationary.



5. Front End Nub

- May be variation of coupled FIN/RIN and local surge.



6. * Contracting Bookend Vortex w/ Increasing Rotational Velocity

- Low level Vr ≥ 25 kts.

7. Tight & Strong Mesovortex (no example)

- Low level Vr ≥ 25 kts.

8.* TDS

(no example)

8 Scenarios

Any one of the 8 scenarios met with the three ingredients is often worthy of a * Tornado Warning. Multiple scenarios present should further increase confidence in a TOR.

Nudgers are secondary, and should add confidence in issuing a TOR when one of the scenarios and the three ingredients are present.

** Three ingredients not necessary to issue a TOR with a contracting bookend vortex (#6) or TDS (#8).*

Send feedback to michael.mathews@noaa.gov

4 NUDGERS

1. Reflectivity Tag About to Intersect Surge

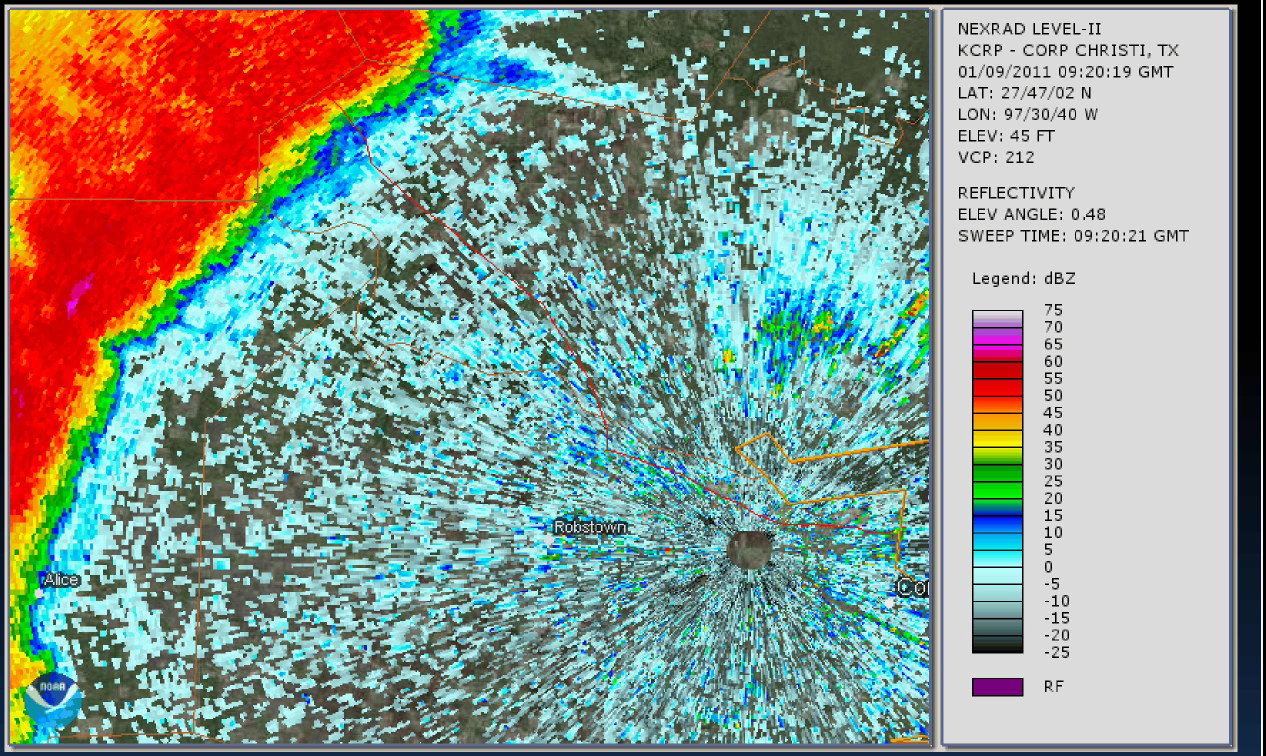
2. 0-3 km ML CAPE ≥ 40 J/kg

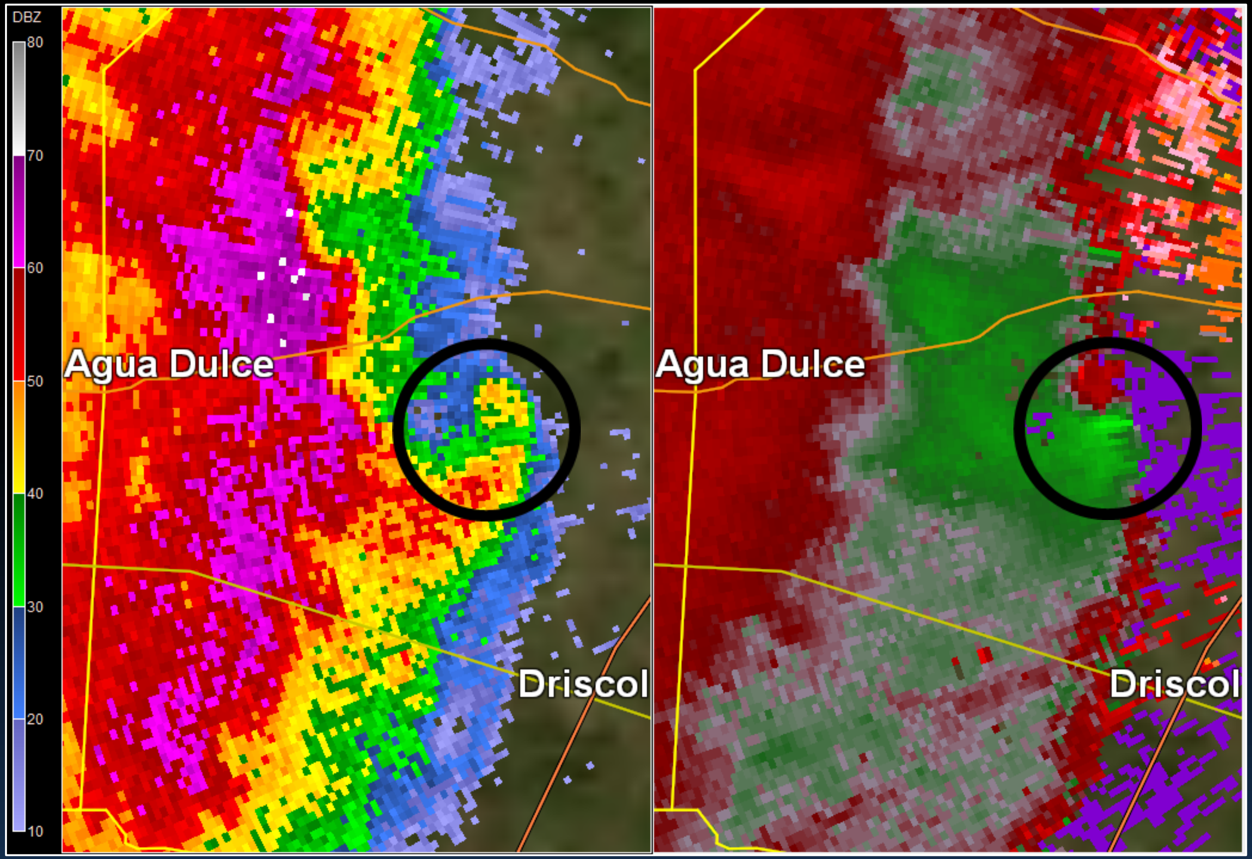
3. Reflectivity Spiking Up Near Surge

- Often ahead of line & may only be viewable at higher slices.

4. History of TDS's

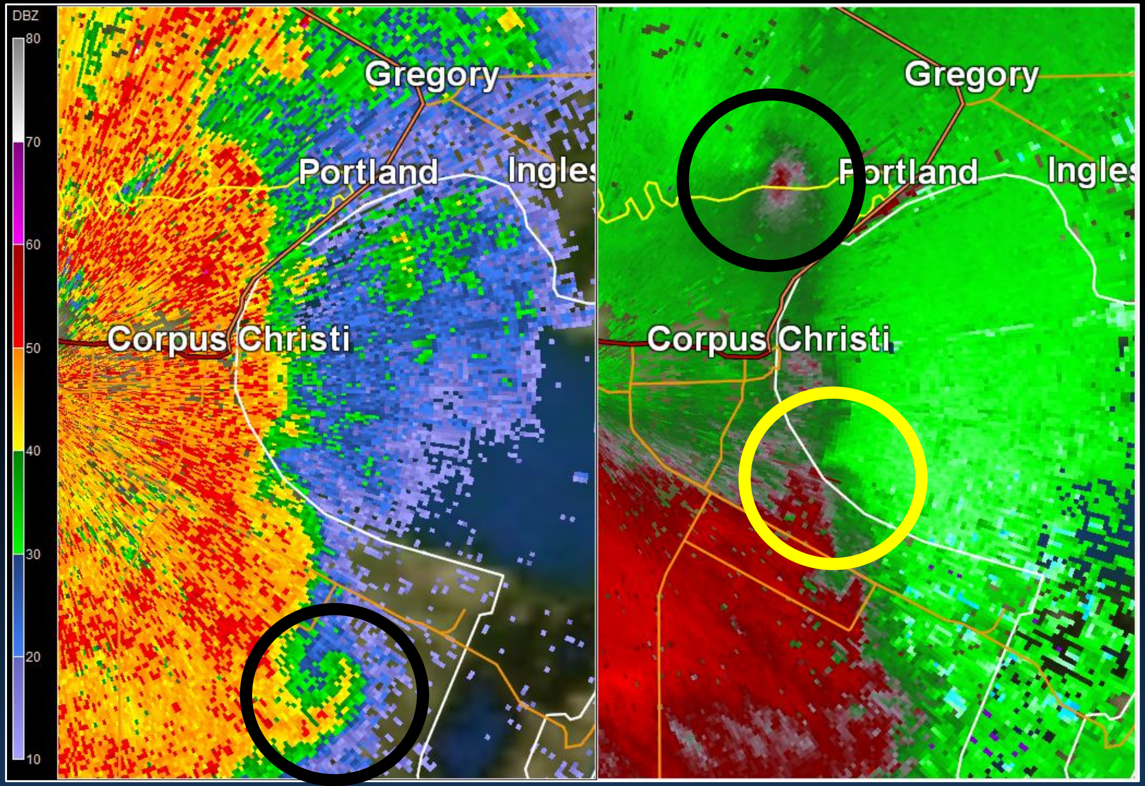
Jan 9, 2011 EF-1 Mesovortex Tornado: First ever Torndao recorded in January!



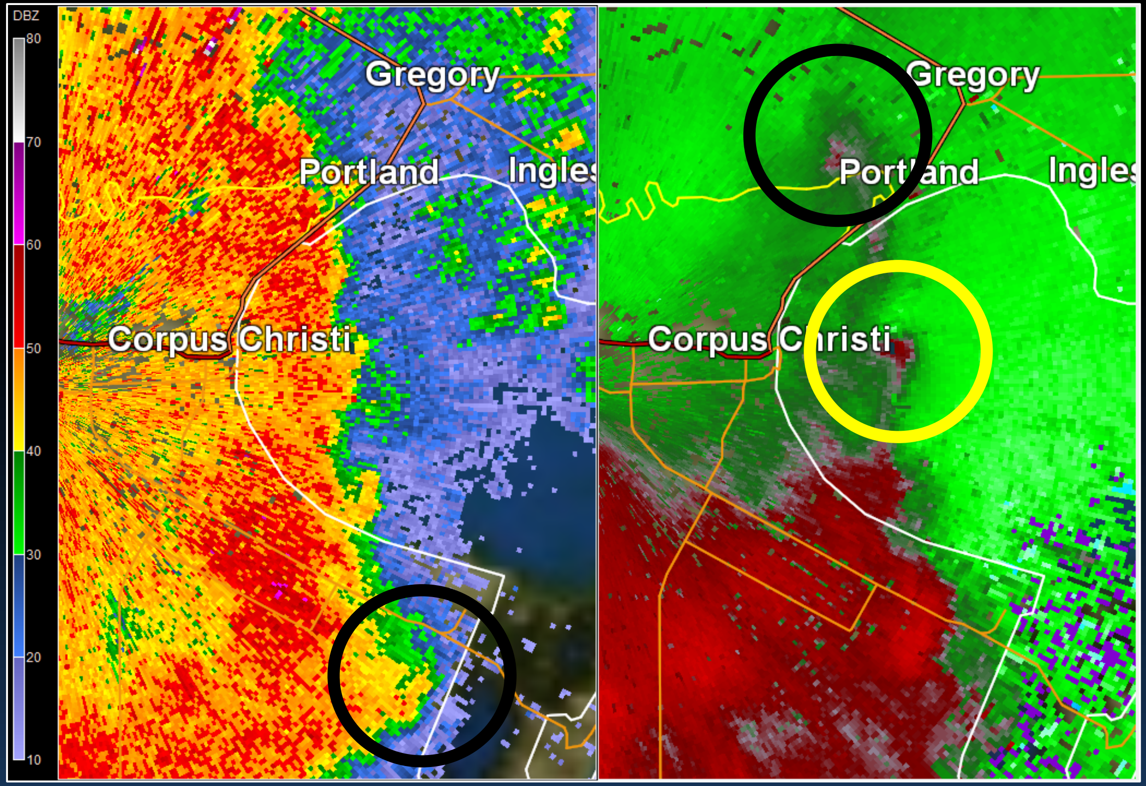


May 15, 2015 Multiple EF-0 Tornadoes: Gregory and Flour Bluff

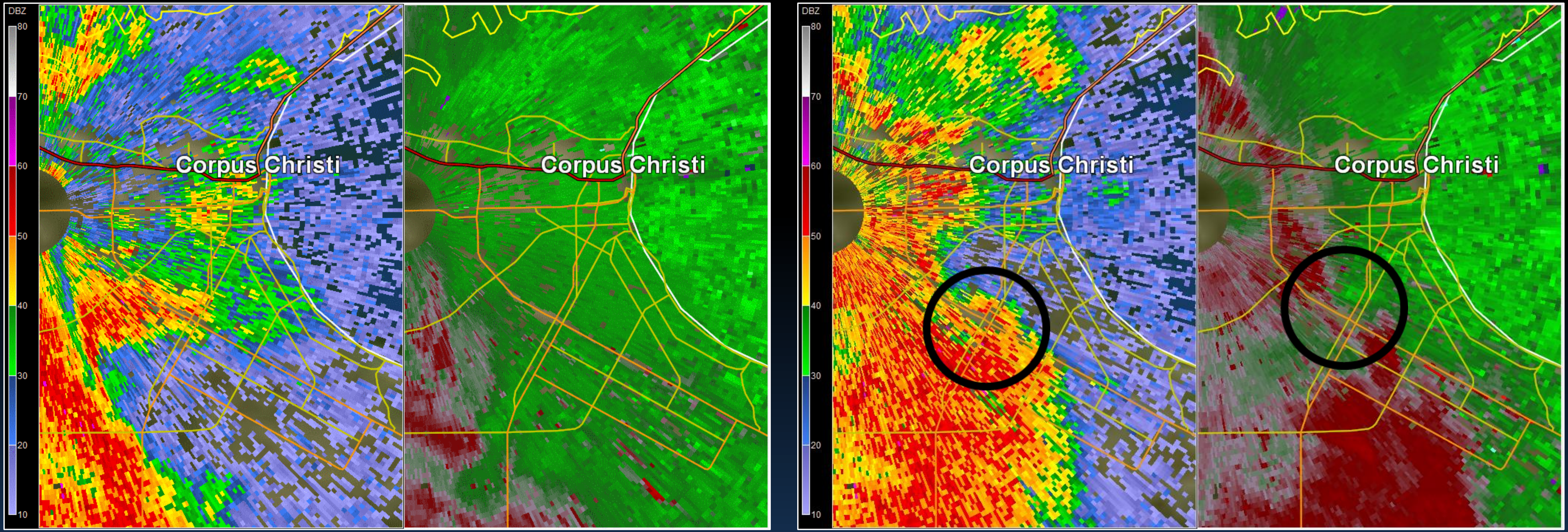
1805Z



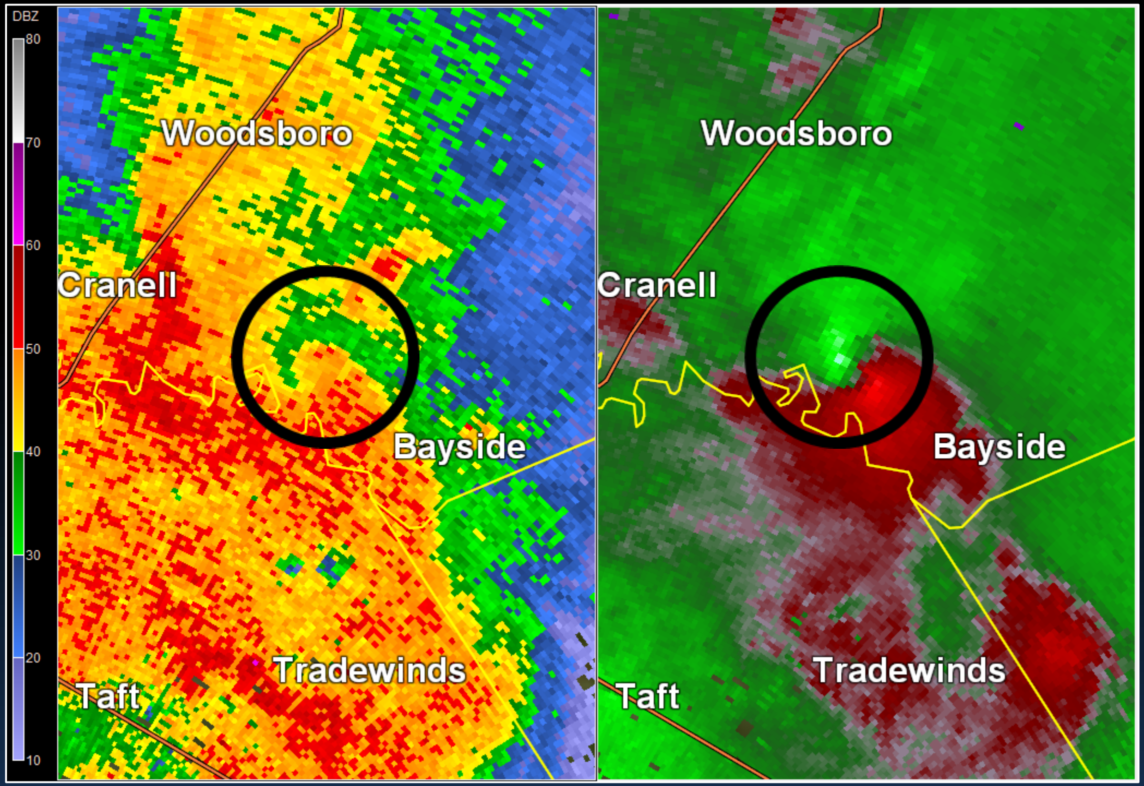
1810Z

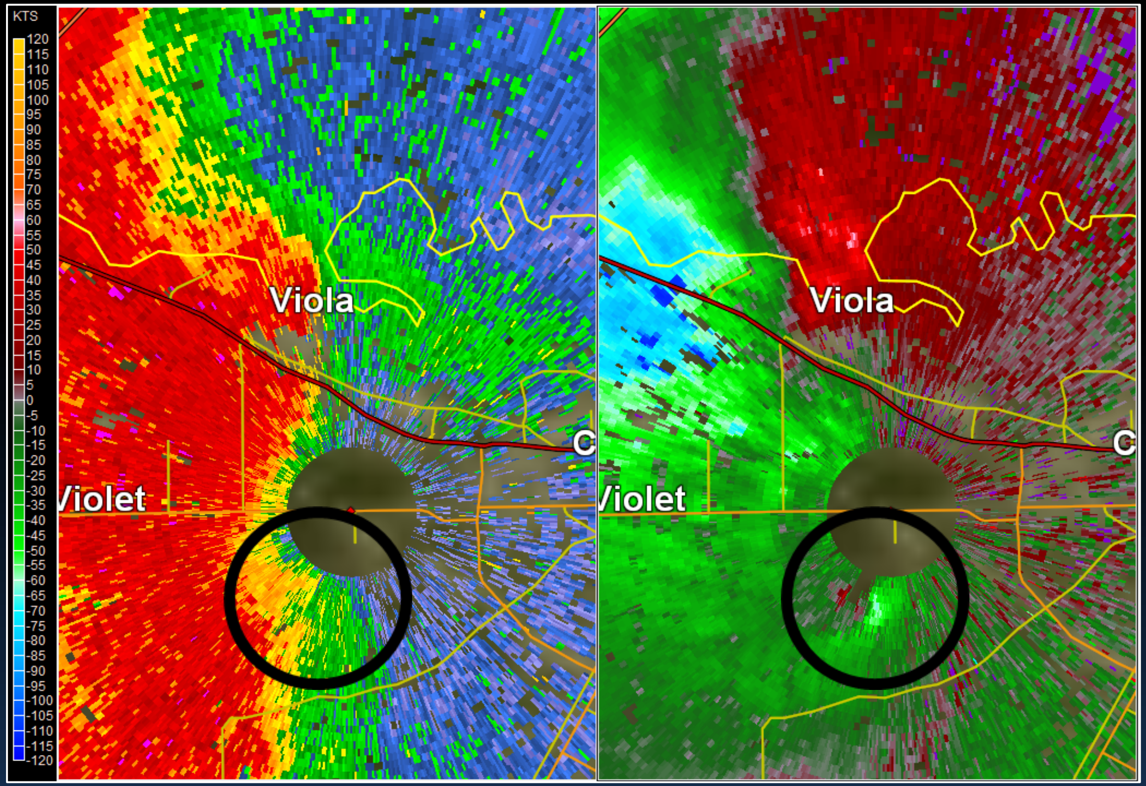


May 24, 2015 Brief EF-1 Tornado: Downtown Corpus Christi

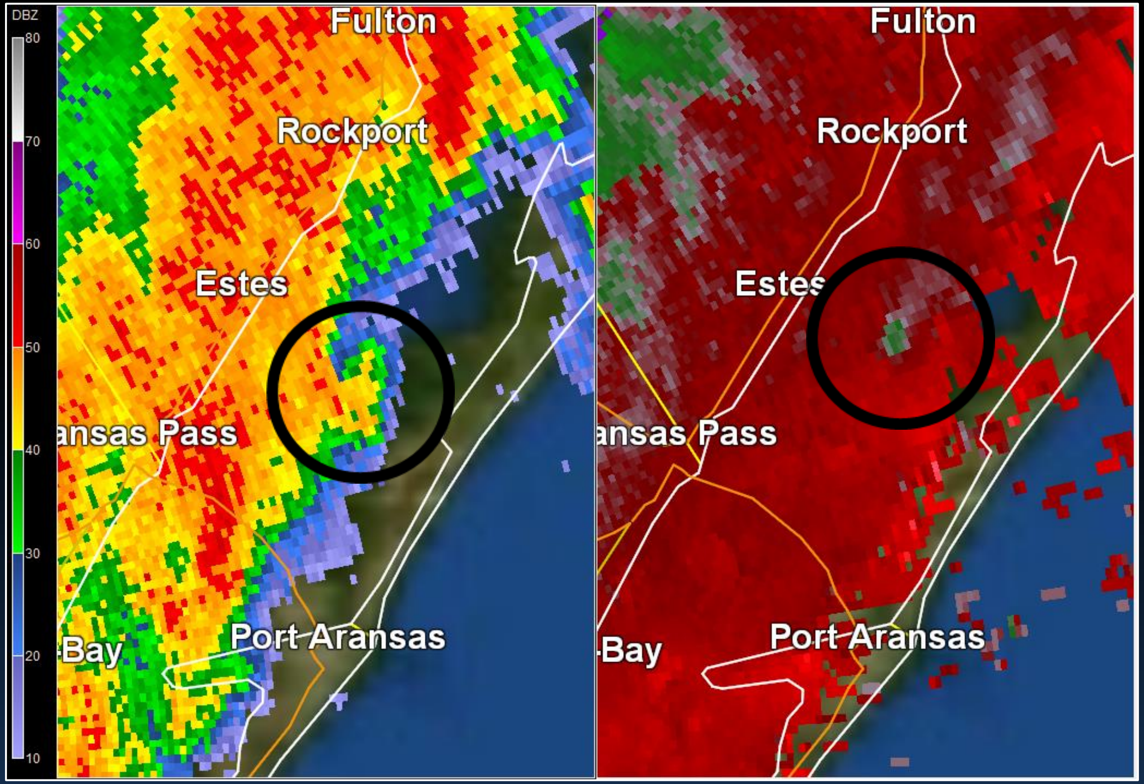


May 10, 2012 Multiple Tornadoes (Not all pictured)

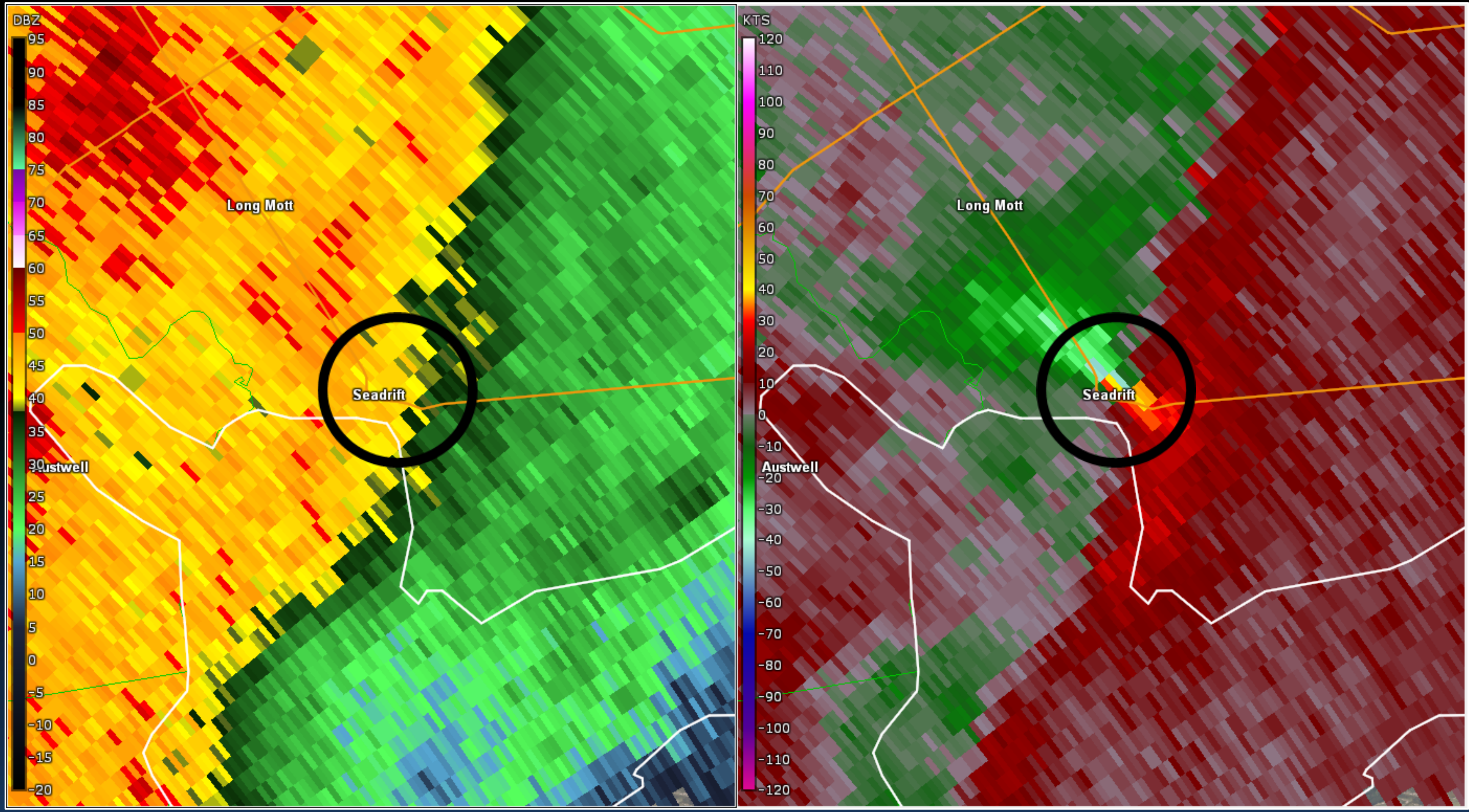




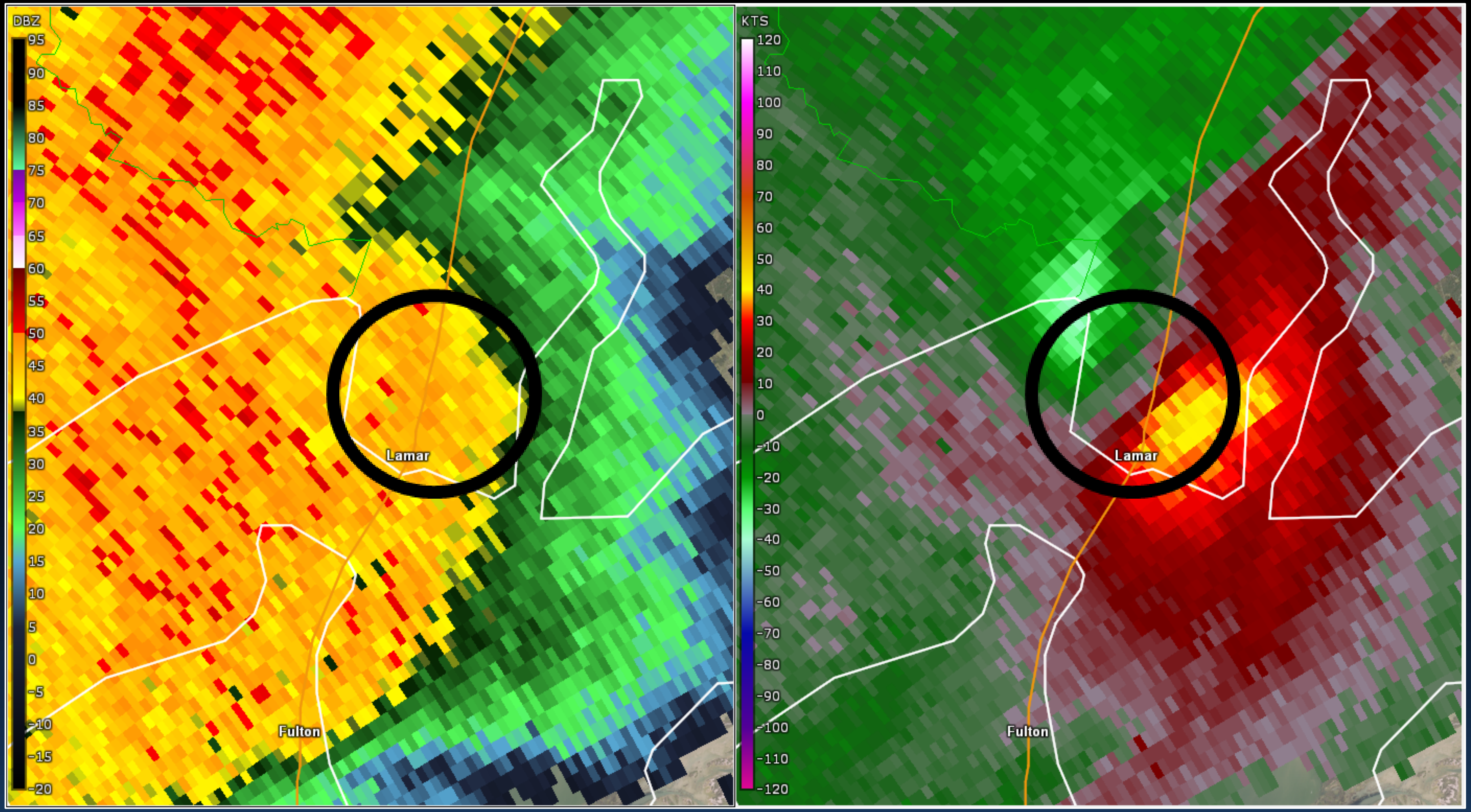
Waterspout over Aransas Bay: Feb 14, 2017 ~800 AM



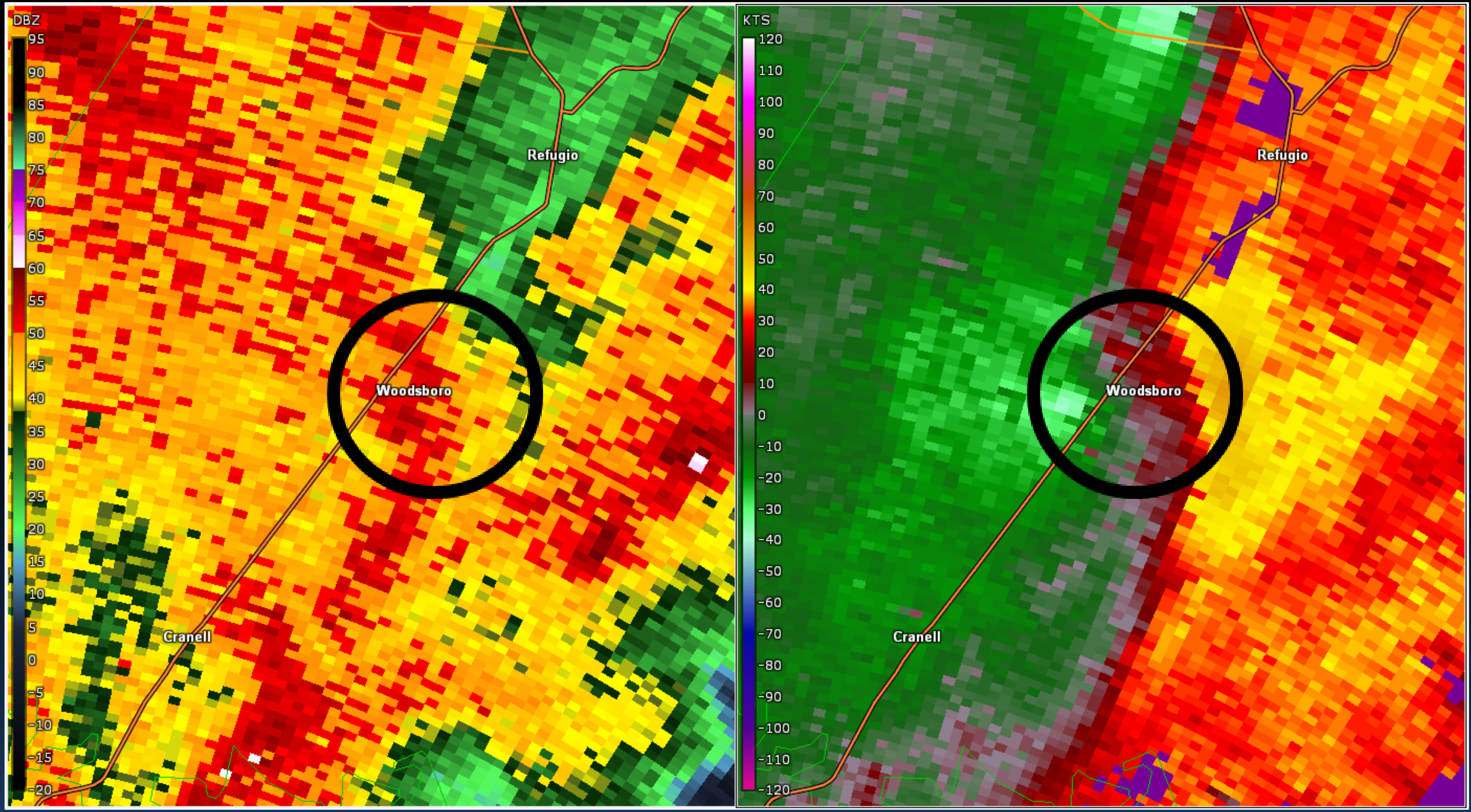
March 29, 2018 Seadrift EF-1 Tornado



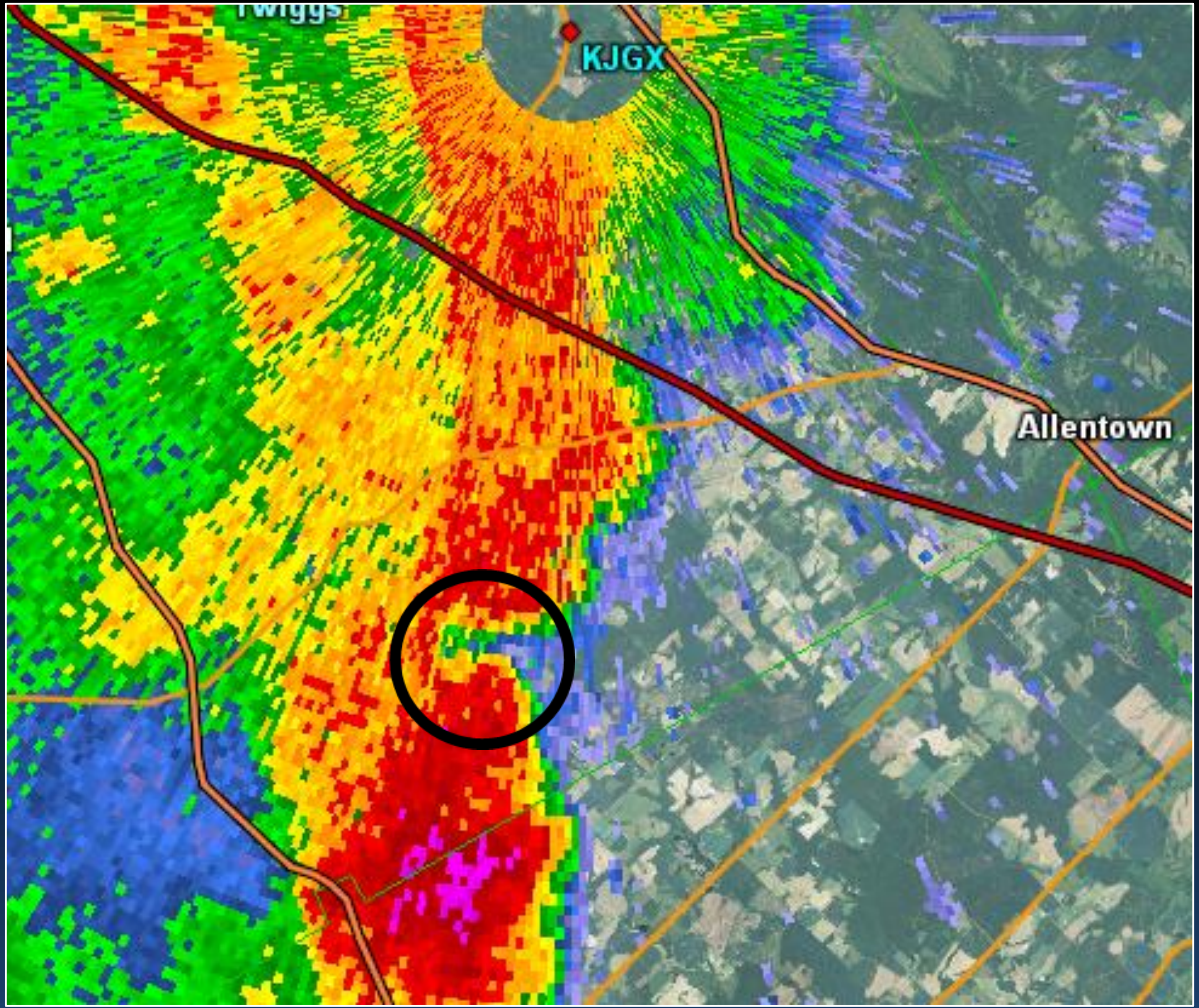
March 29, 2018 Holiday Beach EF-0 Tornado

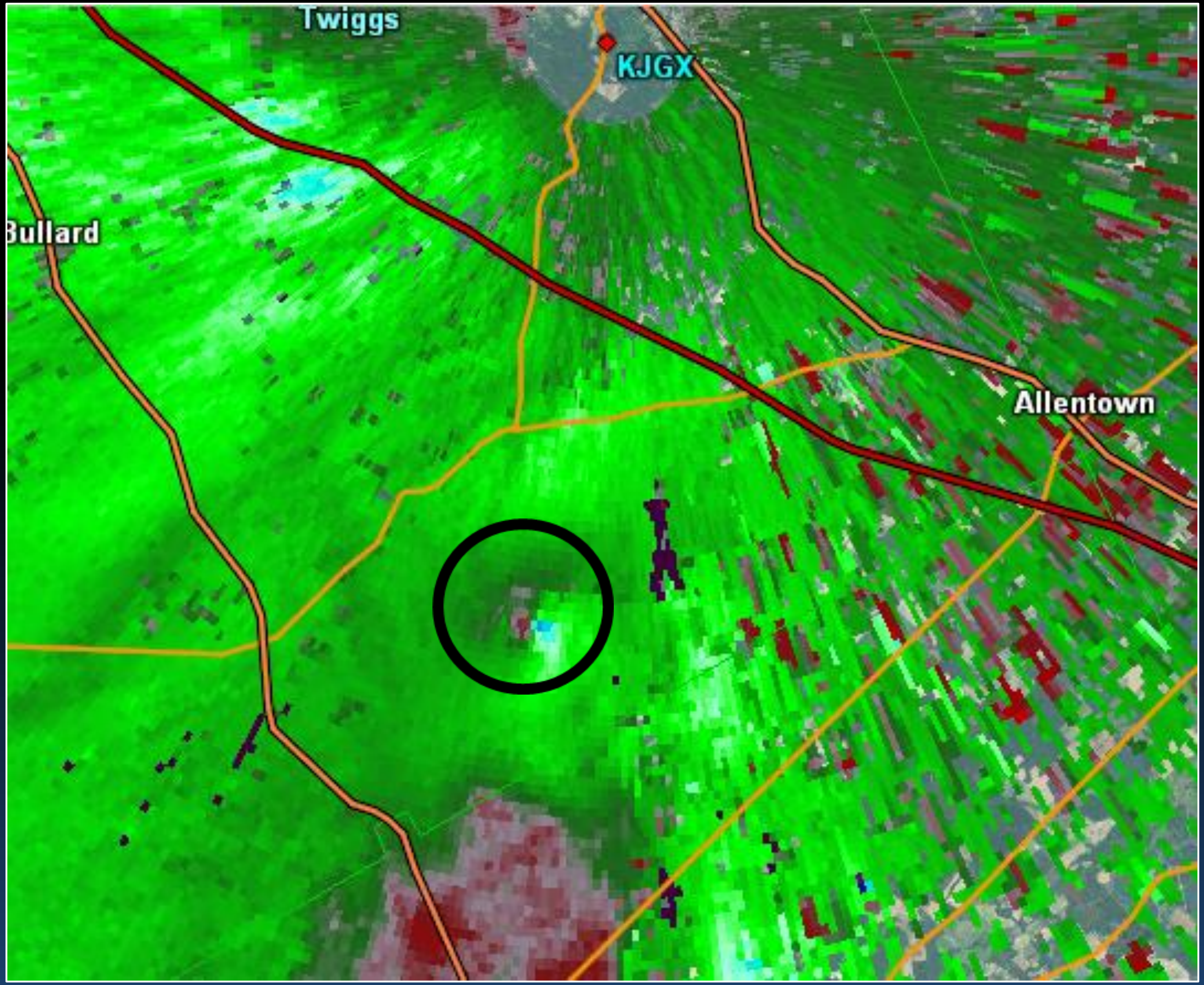


March 29, 2018 Woodsboro EF-0 Tornado

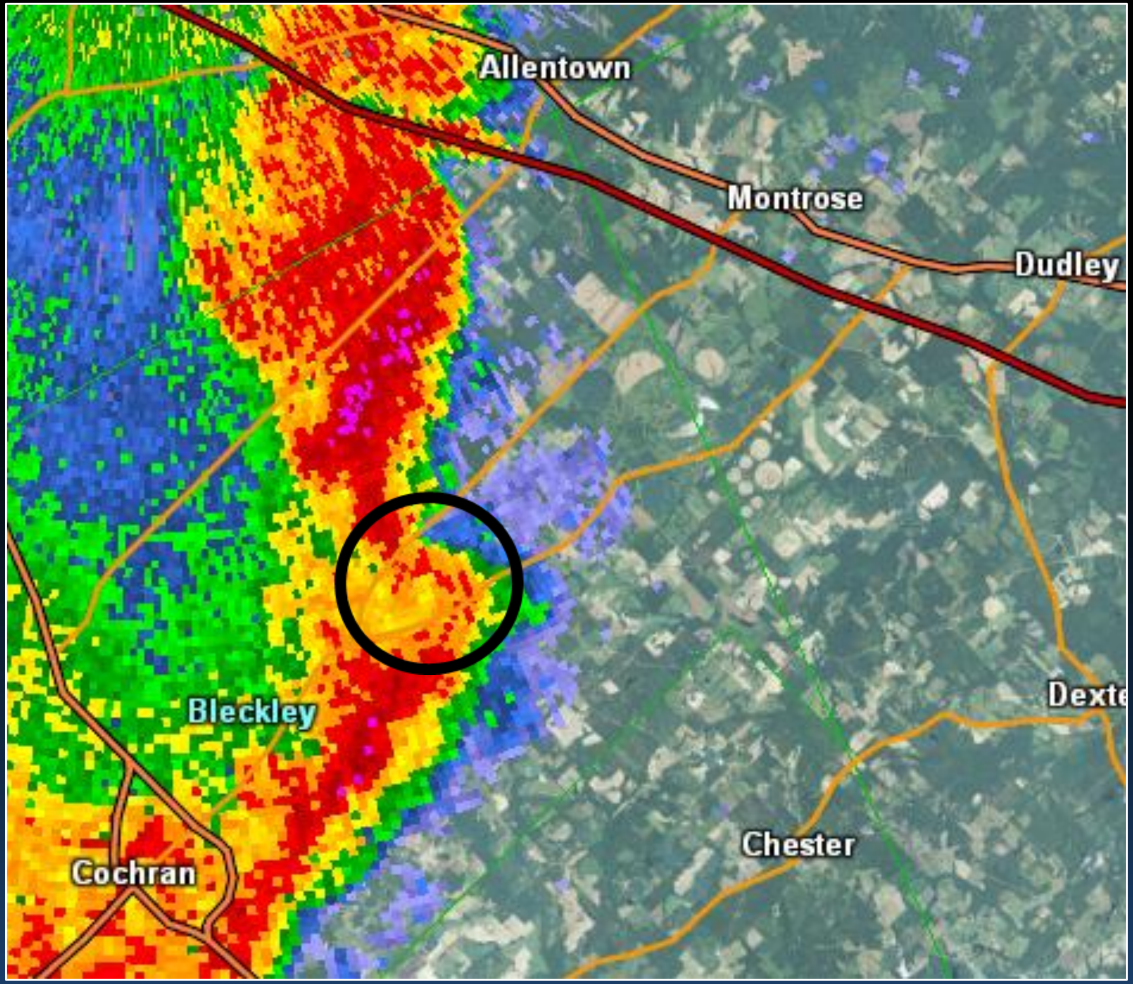


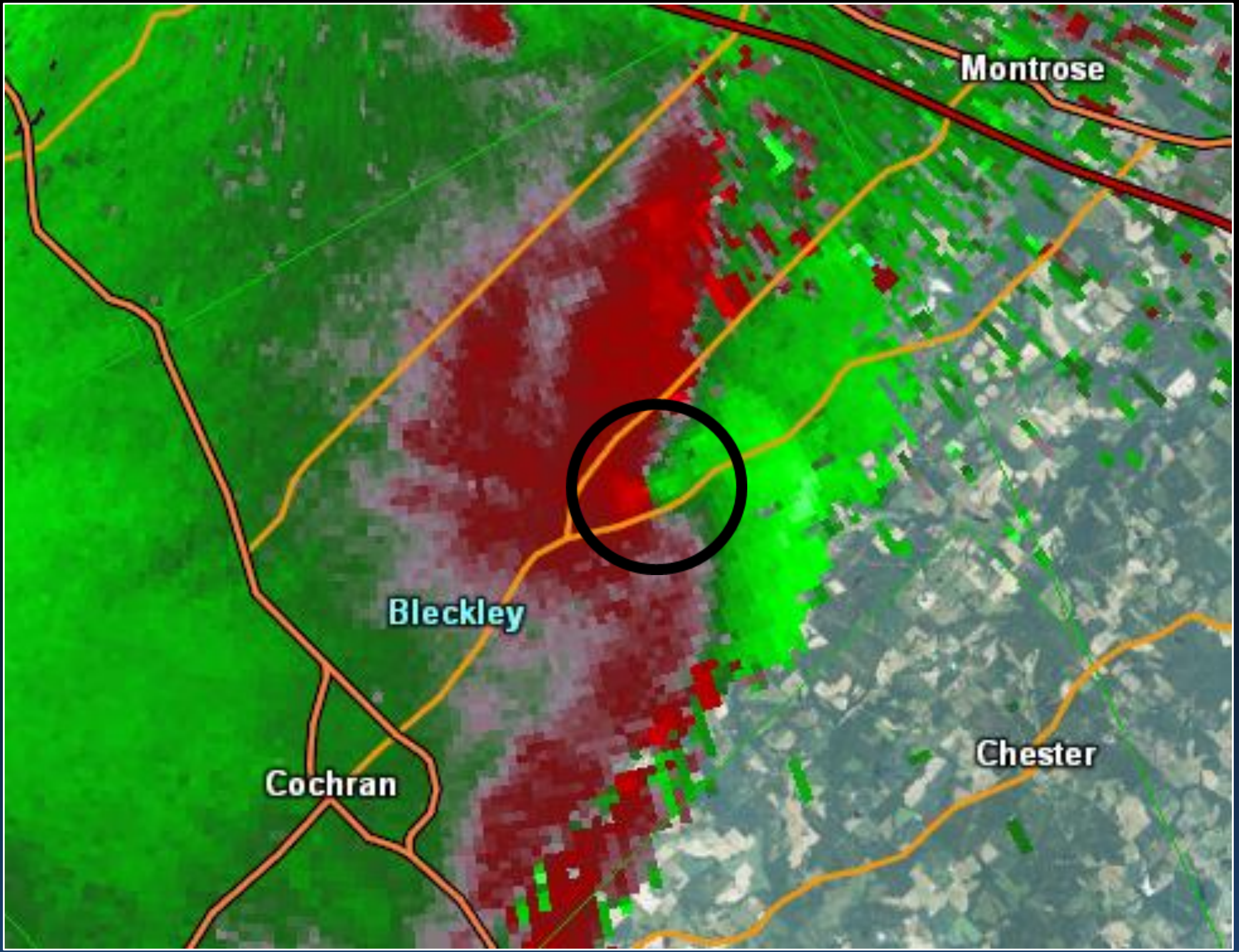
EF-0 Mesovortex Tornado: Twiggs County, Georgia on 1/21/17



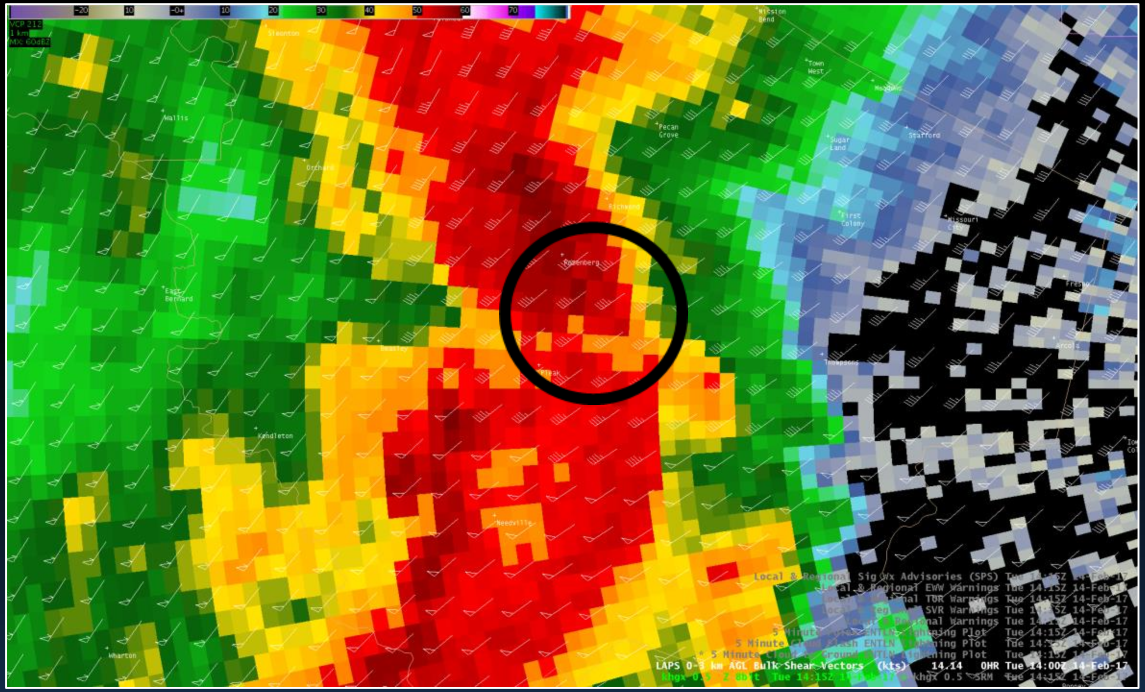


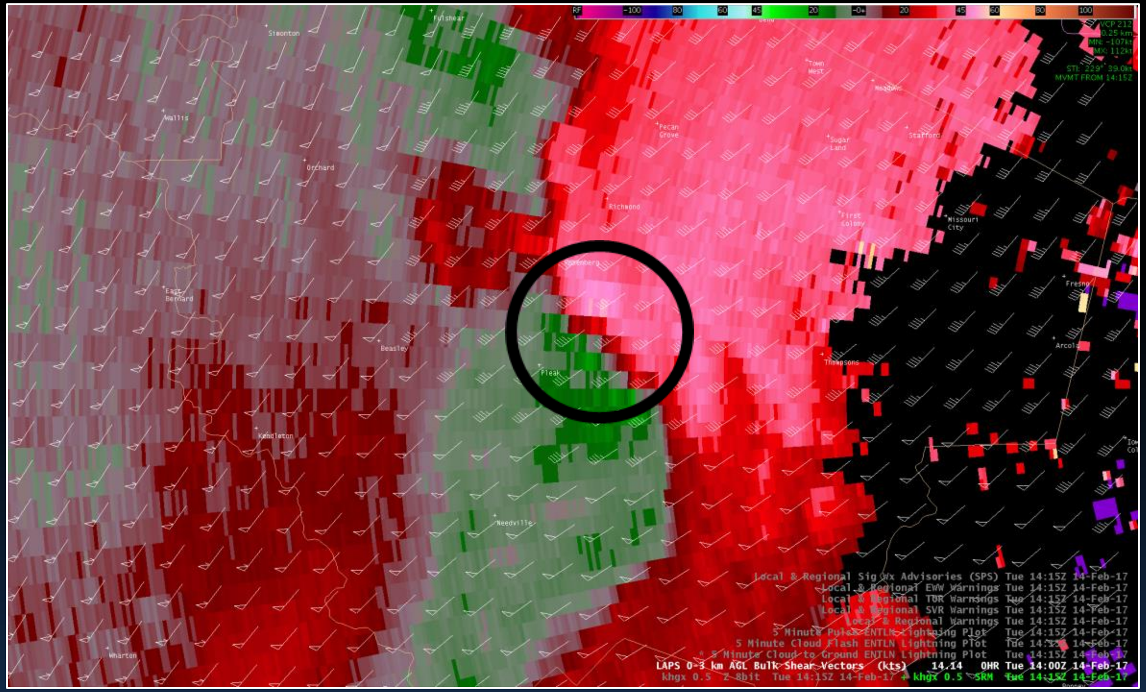
EF-1 Mesovortex Tornado: Bleckley County, Georgia on 1/21/17





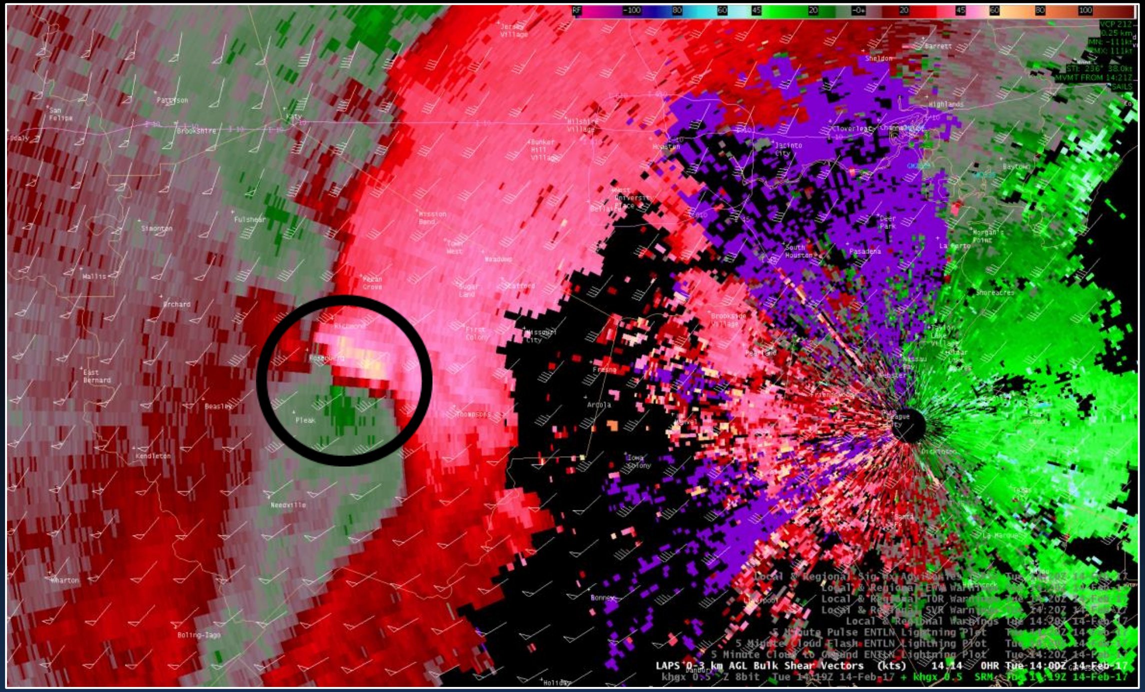
Mesovortex Tornado:
Fort Bend County TX 2/14/17



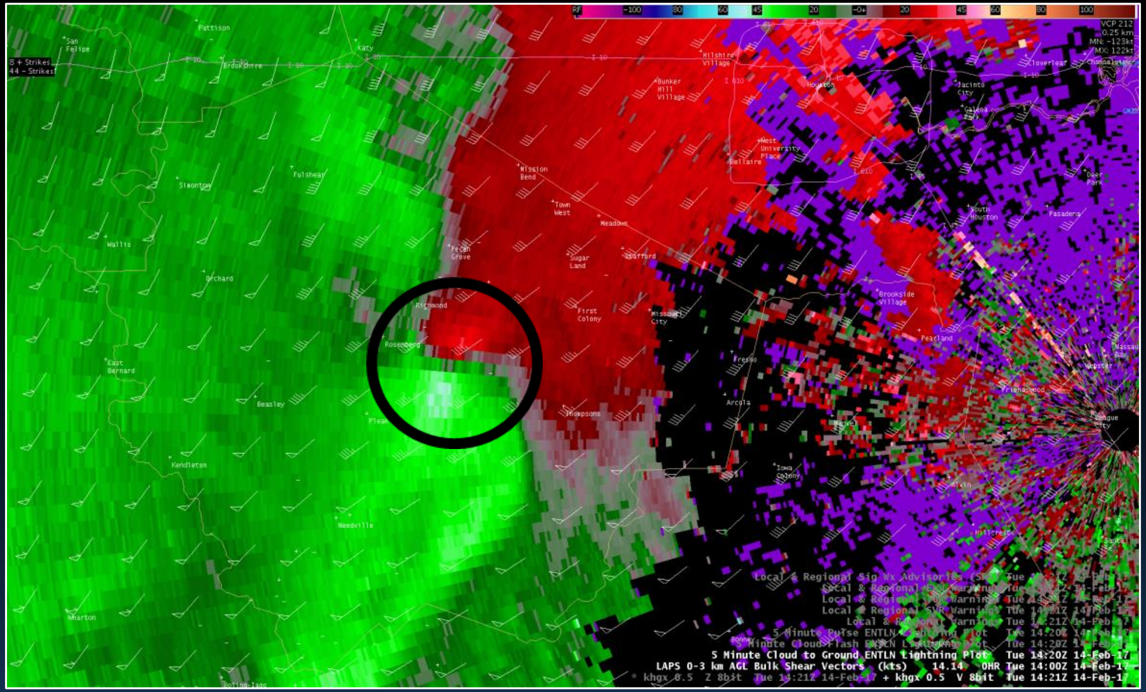


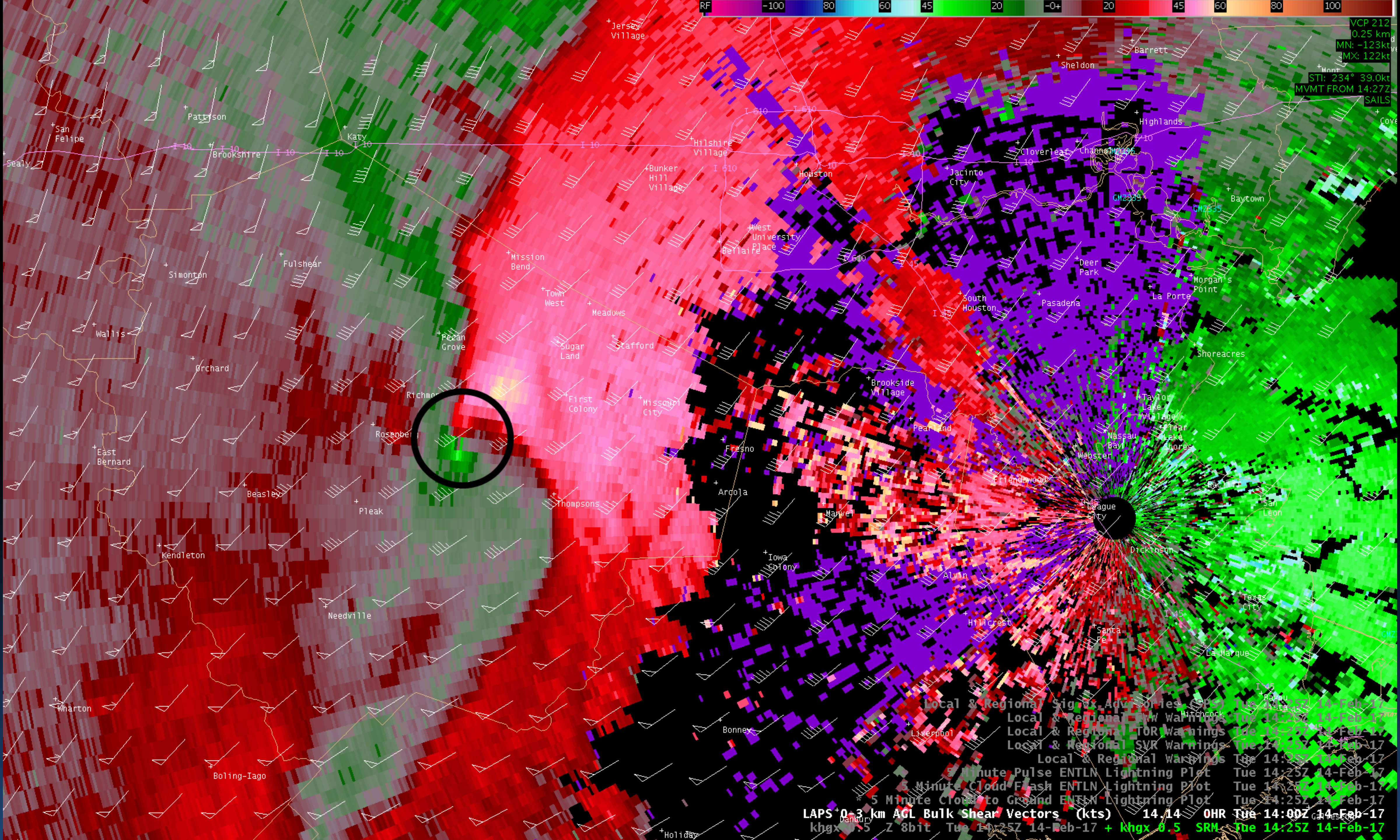
Fort Bend County Tornadic Mesovortex

SRM at 1419Z



V at 1421Z

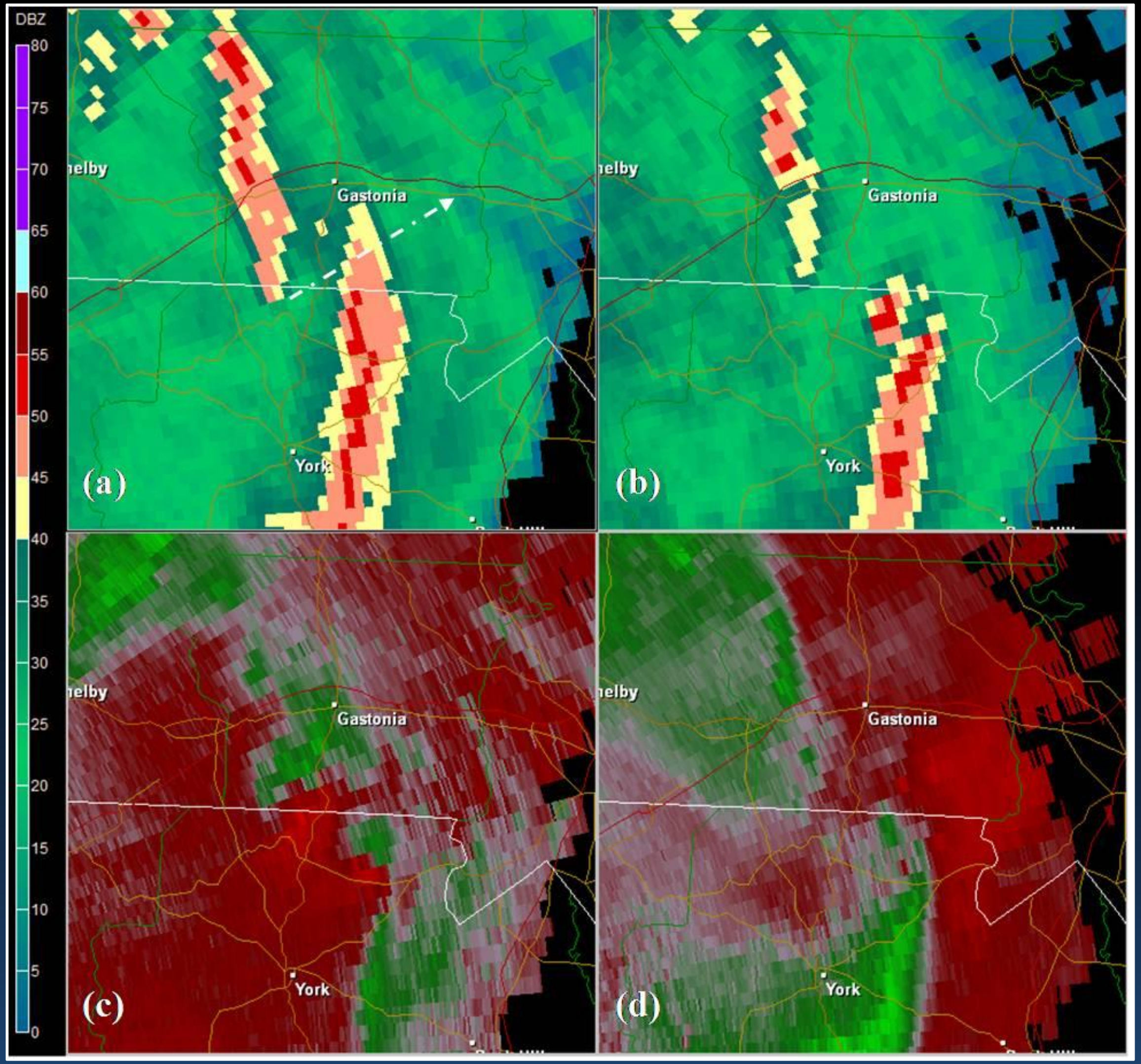




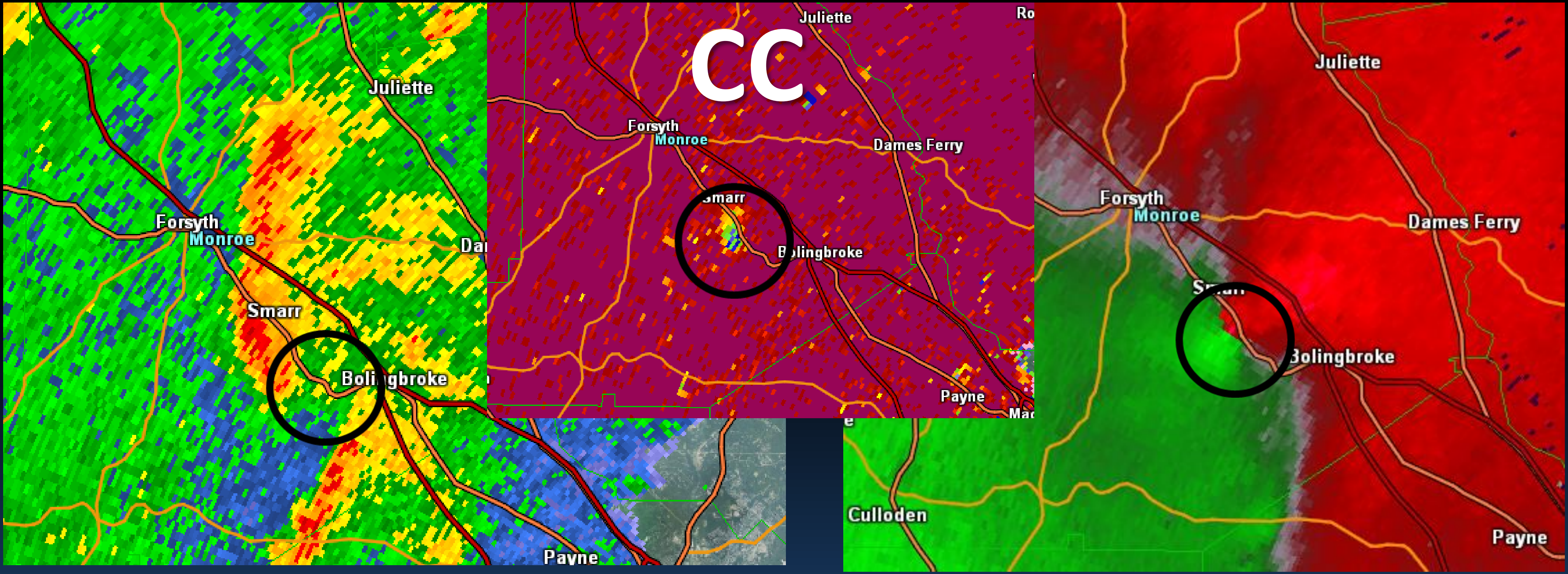
RF
-100
80
60
45
20
-0+
20
45
60
80
100
VCP 212
0.25 km
MN: -123kt
MX: 122kt
STI: 234° 39.0kt
MVMT FROM 14:27Z
SAILS
Jersey Village
Barrett
Sheldon
Highlands
San Felipe
Pattison
Katy
Sealy
Brookshire
I-10
Hilshire Village
Bunker Hill Village
Houston
I-610
Cloverleaf
Channelview
Jacinto City
Baytown
West University Place
Bellaire
Mission Bend
Fulshear
Simonton
Deer Park
Morgan's Point
Town West
Meadows
South Houston
Pasadena
La Porte
Wallis
Pecan Grove
Sugar Land
Stafford
Shoreacres
Orchard
Brookside Village
Richmond
First Colony
Missouri City
Taylor Lake Village
Rosenberg
Pearland
Nassau Bay
Clear Lake Shores
East Bernard
Fresno
Webster
Friendswood
Beasley
Arcola
Pleak
Thompsons
League City
San Leon
Manvel
Kendleton
Dickinson
Iowa Colony
Alvin
Texas City
Needville
Hillcrest
Santa Fe
La Marque
Wharton
Bonney
Liverpool
Boling-Iago
Holiday
Local & Regional Sig Wx Advisories Tue 14:25Z 14-Feb-17
Local & Regional FFW Warnings Tue 14:25Z 14-Feb-17
Local & Regional TOR Warnings Tue 14:25Z 14-Feb-17
Local & Regional SVR Warnings Tue 14:25Z 14-Feb-17
Local & Regional Warnings Tue 14:25Z 14-Feb-17
5 Minute Pulse ENTLN Lightning Plot Tue 14:25Z 14-Feb-17
5 Minute Cloud Flash ENTLN Lightning Plot Tue 14:25Z 14-Feb-17
5 Minute Cloud to Ground ENTLN Lightning Plot Tue 14:25Z 14-Feb-17
LAPS 0-3 km AGL Bulk Shear Vectors (kts) 14.14 0HR Tue 14:00Z 14-Feb-17
khgx 0.5 Z 8bit Tue 14:25Z 14-Feb-17 + khgx 0.5 SRM Tue 14:25Z 14-Feb-17

"Broken-S" Signature

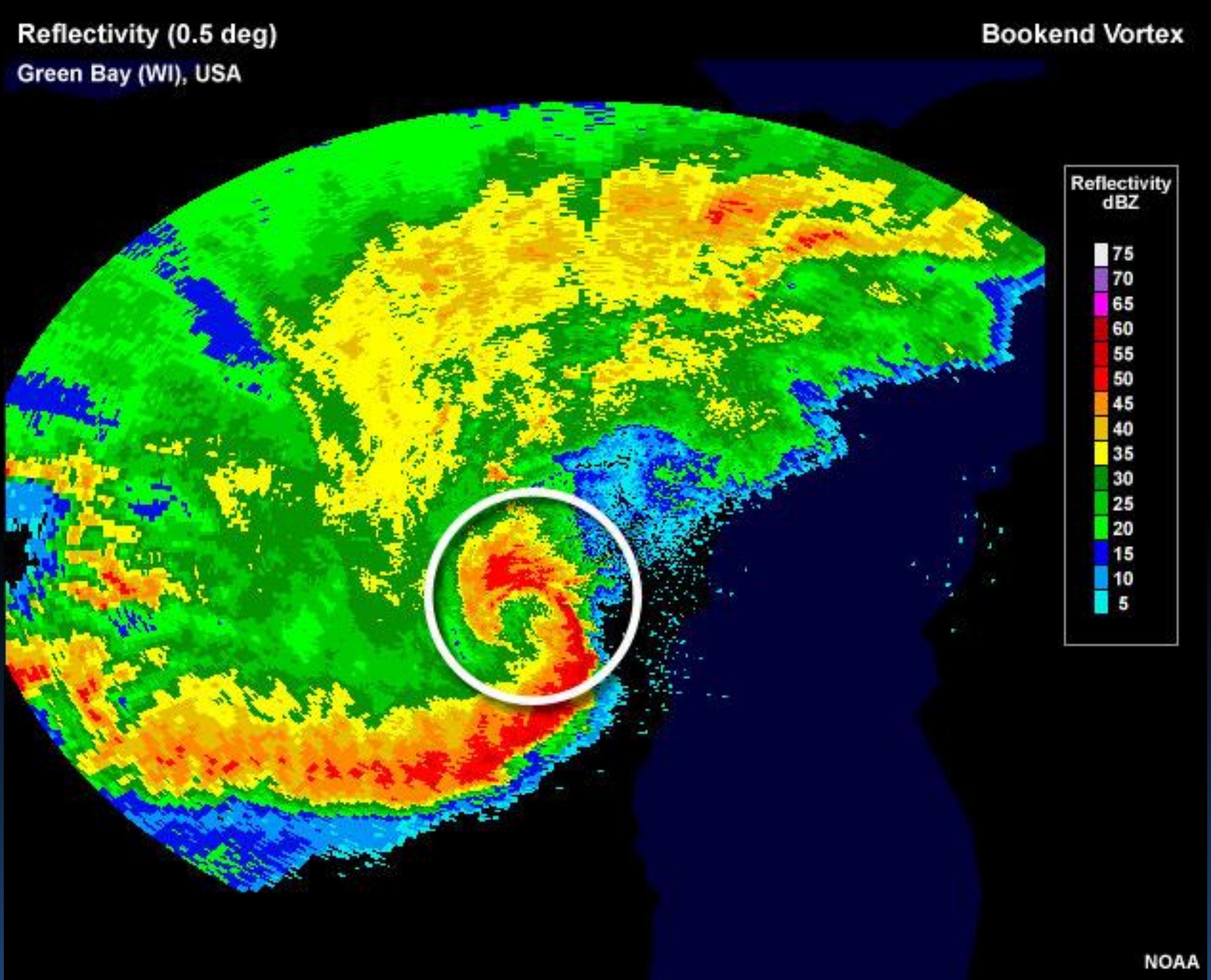
- QLCS Mesovortex
- Mostly Cool Season
- High shear/Low Cape
- Mainly Southeast U.S.



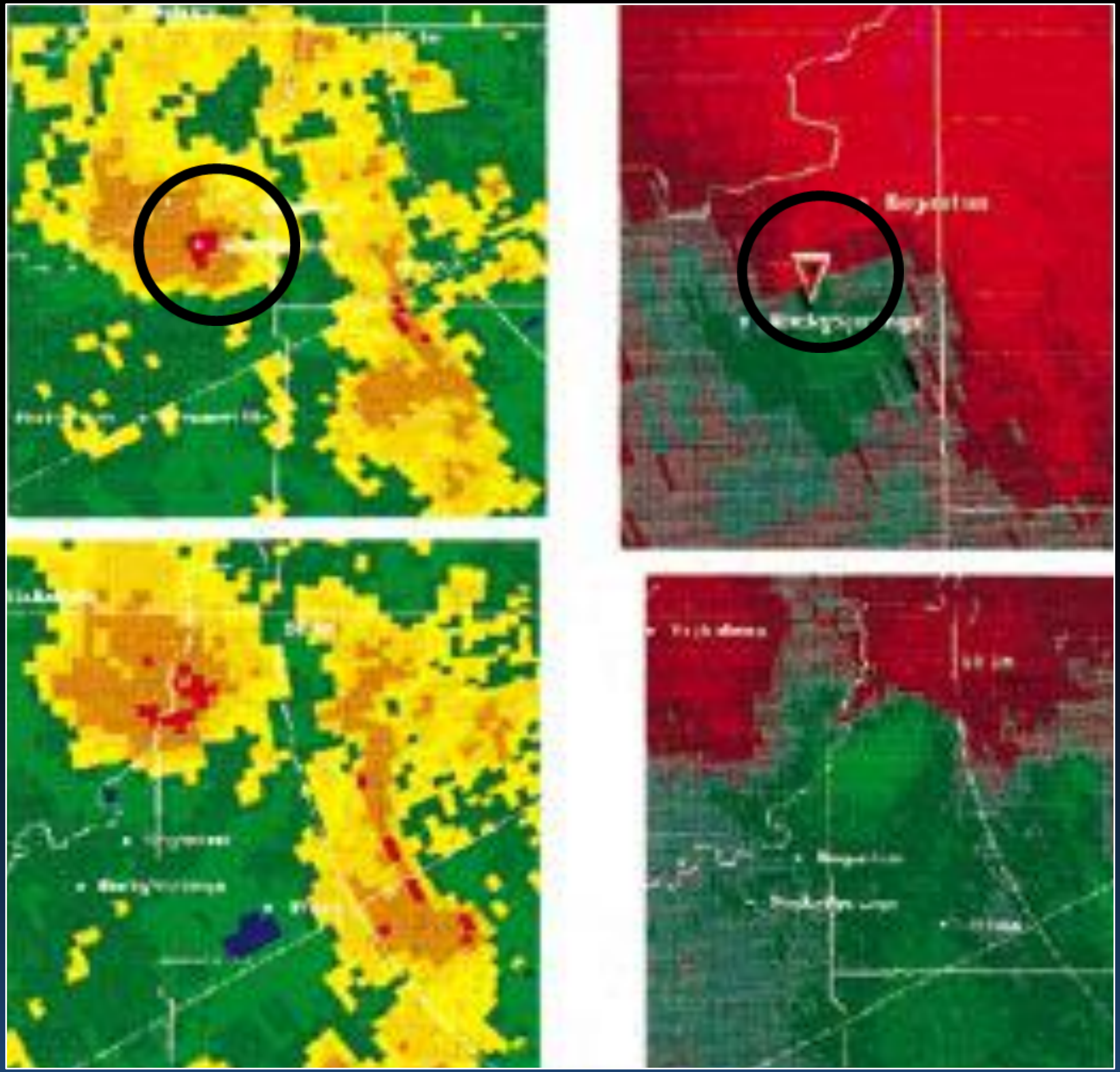
Broken “S” Mesovortex Tornado: Monroe County, Georgia on 1/21/17 ~Noon



Bookend Vortex Tornado

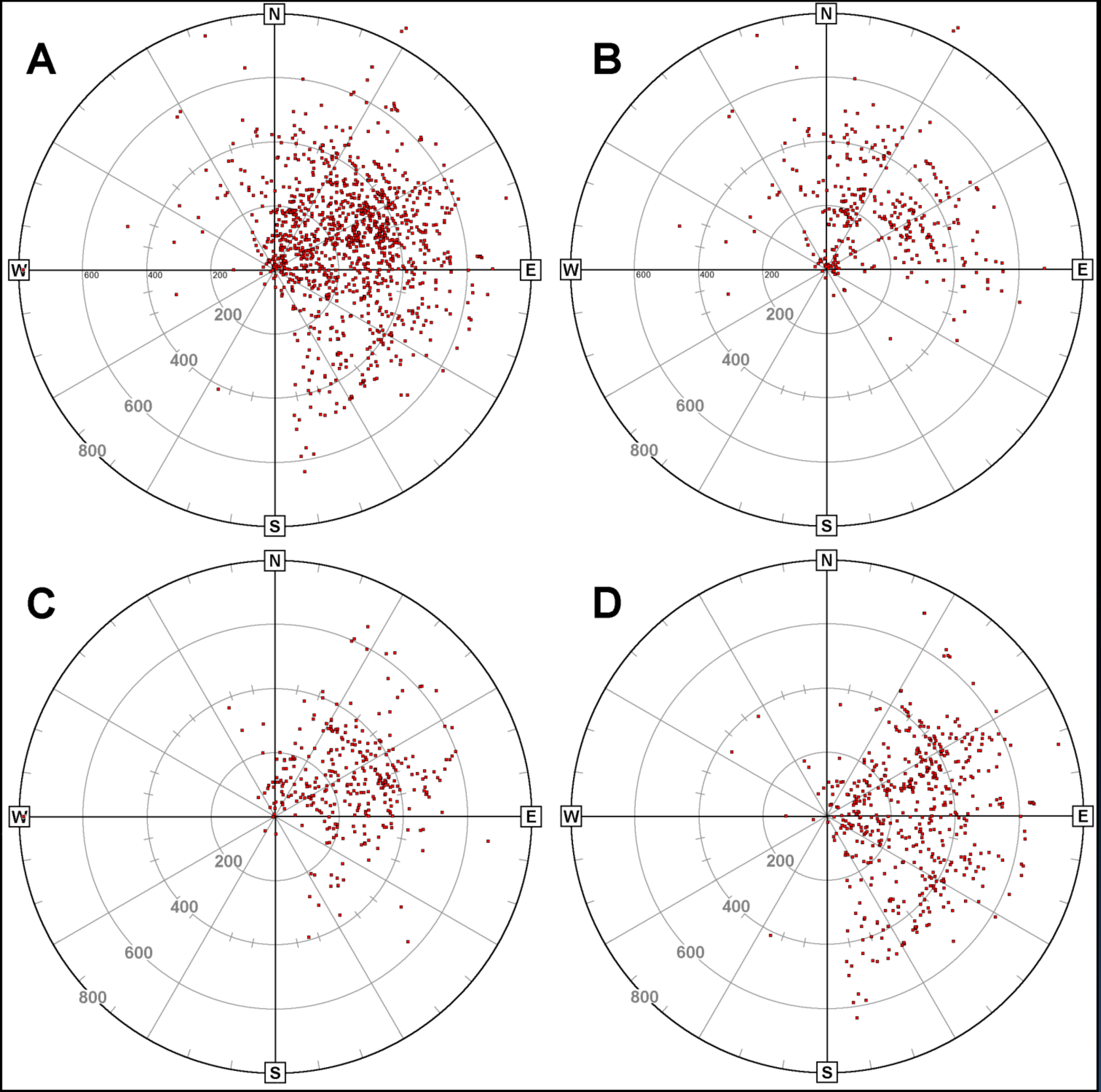

Reflectivity (0.5 deg)
Green Bay (WI), USA
Bookend Vortex
Reflectivity dBZ
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
NOAA

Bookend Vortex Tornado: Natchez MS, 5/8/1995



Tropical Cyclone Tornado Techniques

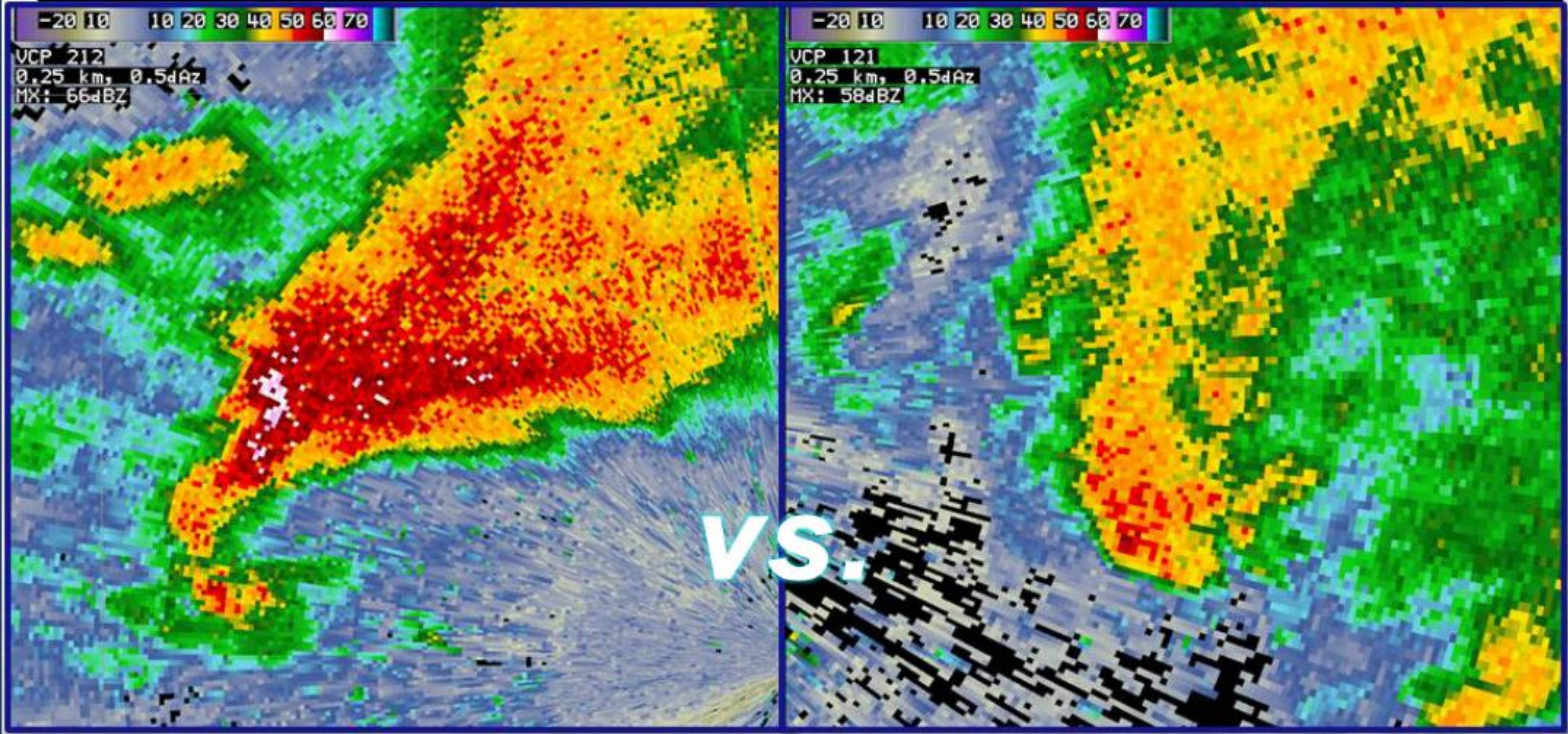
Tropical Cyclone Center-Relative Plots of Tornadoes



A) All Tropical Cyclones
B) Hurricanes
C) Tropical Storms
D) Tropical Depressions, Remnant Lows, and TC remnants.

Events plotted with respect to north-relative azimuth. Reference frame is with respect to north.

Source: Roger Edwards, EJSSM 2012



Tornadic Classic Supercell

Tornadic TC Supercell

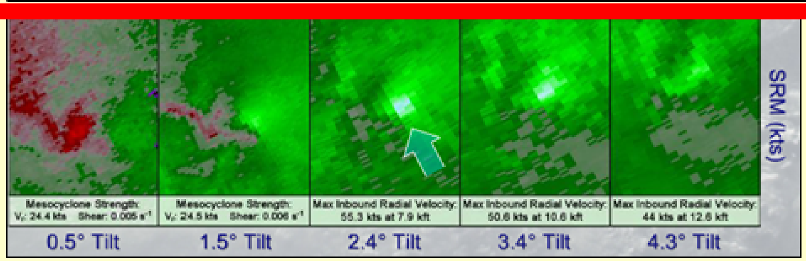
Radar Recommendations

- VCPs 12 or 212.
- Look at both V and SRM.
- Modify default storm motion given the varying motions around the center of the storm.
- Comparison of KDP and ZDR.
  - "Sorting"

Tropical Cyclone Tornado Guidance (WDTB, 2014)

Range from Radar	LL V_{rot}	LL Shear	Circulation Contracting	Inflow Notch or Hook	ZDR/KDP Displacement		Mesocyclonic VES
0-39 nm	*20+ kts*	≥ 0.01 s^{-1}	✓	✓	✓	← *1 of 2* →	✓
40-70 nm	*15+ kts*	✗	✓	✗	✓	← *1 of 2* →	✓
>70 nm	*12+ kts*	✗	✗	✗	✗		✗

Identifying Mesocyclonic VES

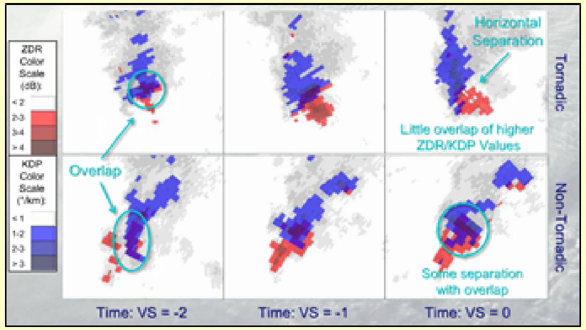


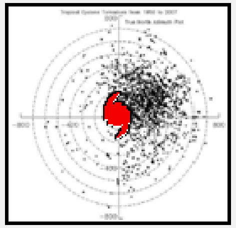
"Velocity Enhancement Signature" – enhanced radial velocities of 30+ knots between 7,000 and 14,000 feet AGL on the right flank of a mesocyclone

- Occurs when storm motion deviates from mean flow, leading to an asymmetric mesocyclone velocity pattern.
- Located above low-level inflow and vertically co-located with the low-level mesocyclone and hook signature.
- WDTB analysis showed about **85% of tornadic events had this signature** while about 42% of non-tornadic events did.
- **Max values generally 1-4 volume scans before the tornado.**

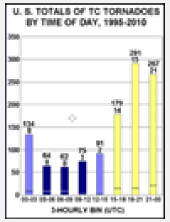
Horizontal Displacement of ZDR/KDP

- Implies size sorting of hydrometeors from increased directional shear within the storm due to strong mesocyclone development.
- Maximum KDP values displaced left of the maximum ZDR values relative to the mean storm motion.
- Can be detected in storms greater than 40 nm from radar.
- WDTB analysis: **70% of tornadic events had this signature** while about 58% of non-tornadic events did.





Most occur in right front quadrant of the TC and within 300mi of center. 80% occur from 350° to 120°



Mid-afternoon peak (19-21Z), earlier than non-TC peak. More nighttime events than non-TC.

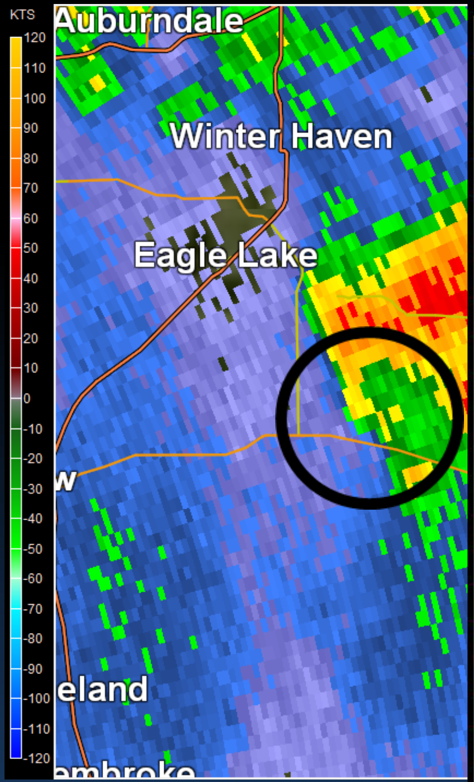
INGREDIENTS

- 200mb jet streak NE of cyclone
- Organized, large, directionally symmetric wind field at 850mb
- Reduced RH at 700-500mb
- Baroclinic boundaries.
- Mid-level RH should not be too dry, limiting convection
- 0-1km SRH generally above 170 m^2/s^2 (*supercell tors*).
- 25th and 75th %-ile MLCAPE is 320 and 870 j/kg (*supercell*)

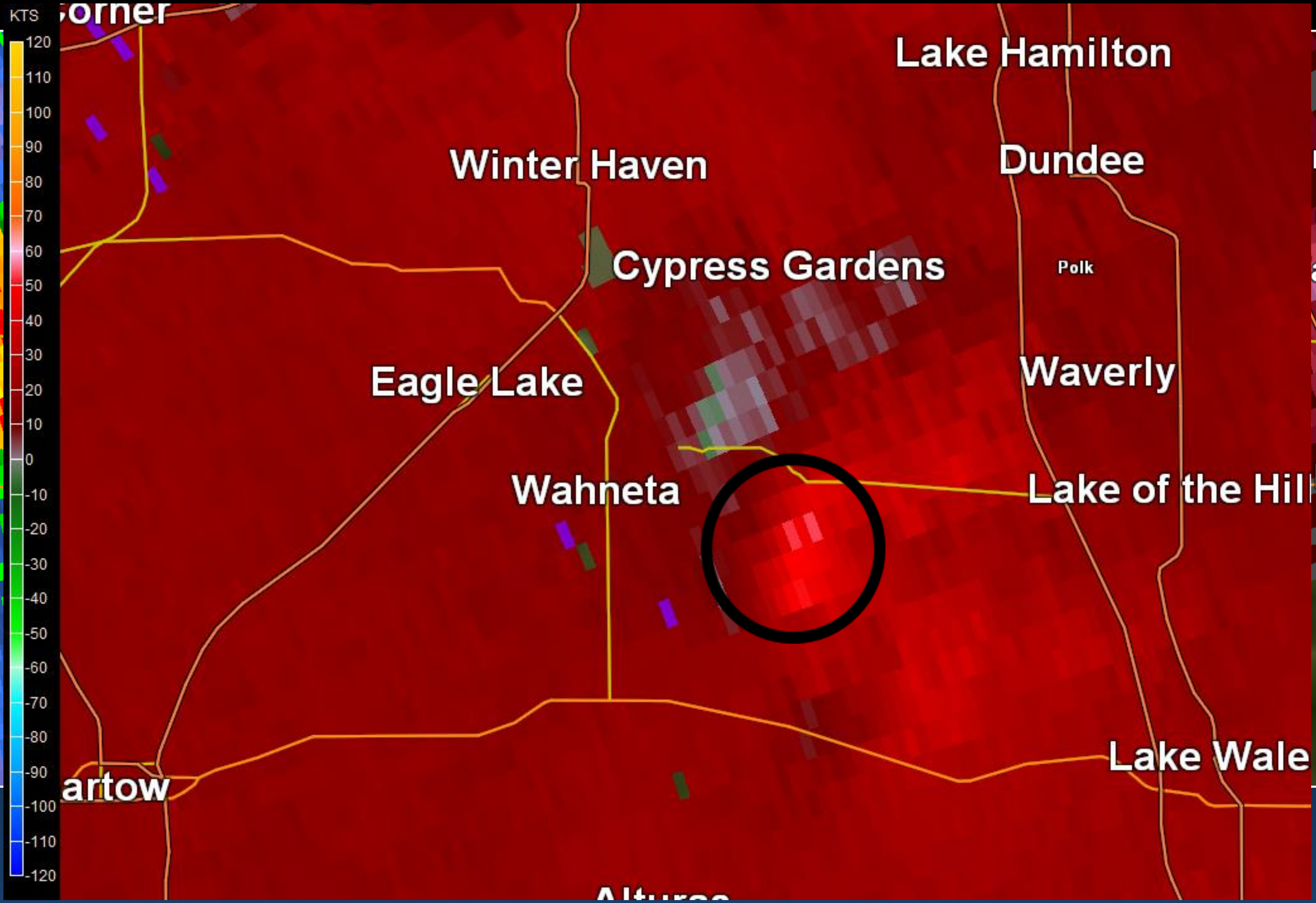
Produced by Alex Lamers, NWS TLH

Tropical Storm Debby – June 25, 2012 0004Z
EF-2 Tornado in Polk County east of Tampa Bay

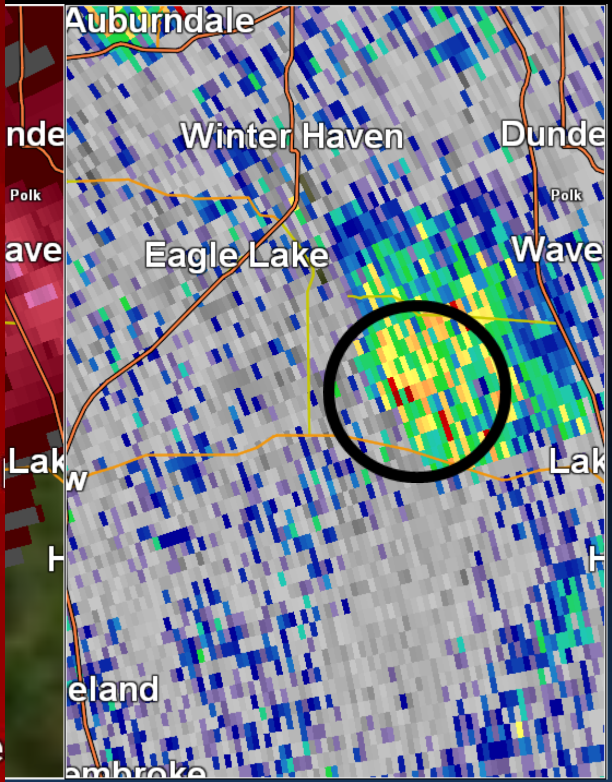
Hook Echo and LLRV ~ 35 kts



Velocity Enhancement Signature ~ 54 kts

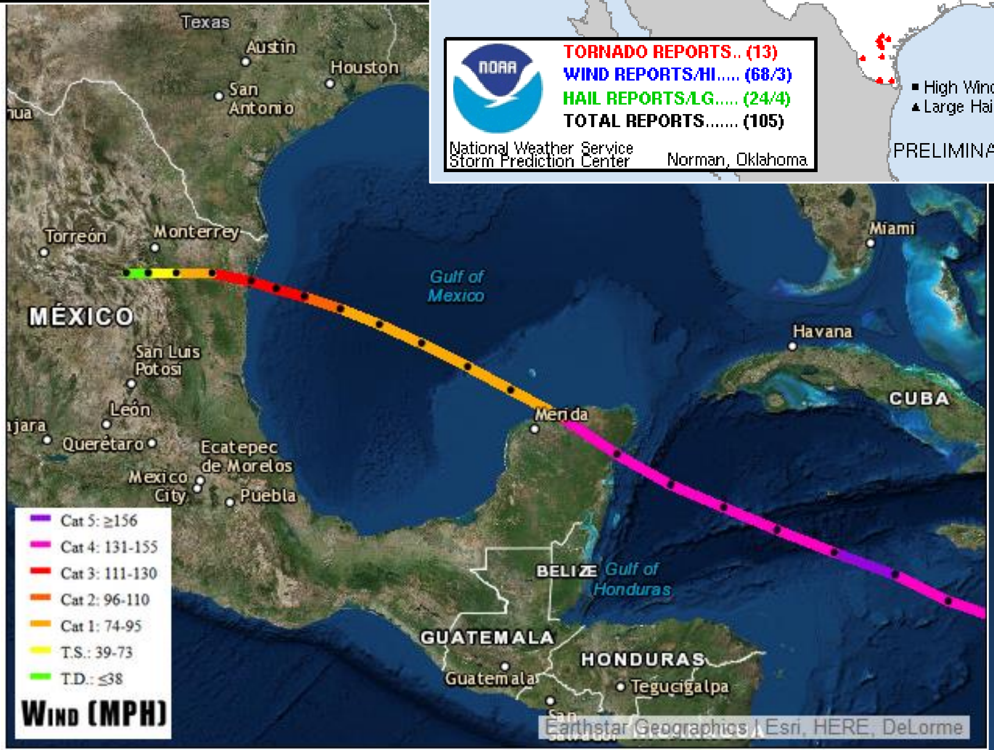


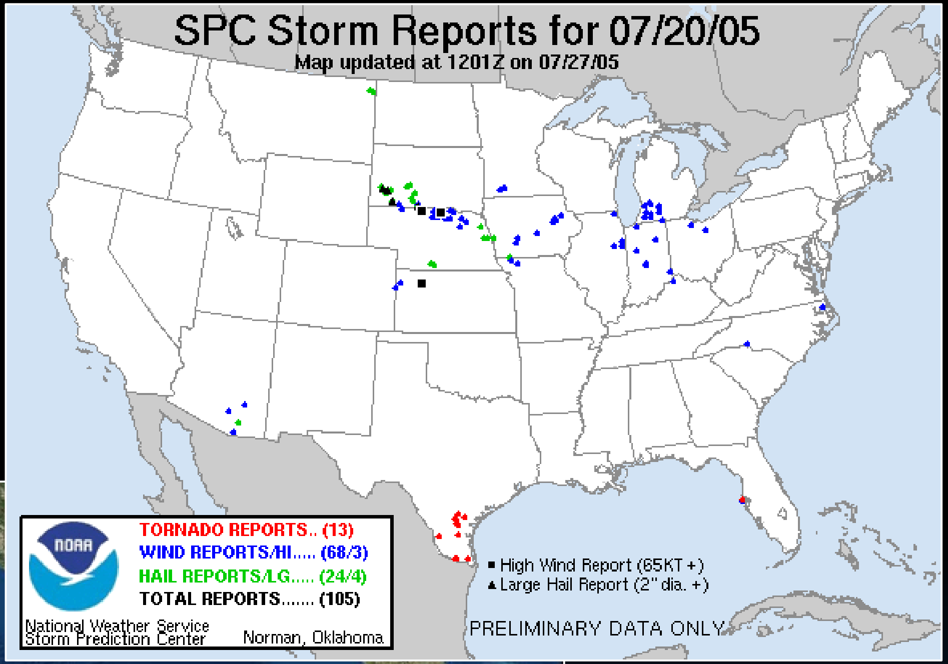
Max KDP displaced left of Max ZDR



Hurricane Emily’s 13 Tornadoes – July 20, 2005

EF-0 Premont Tornado

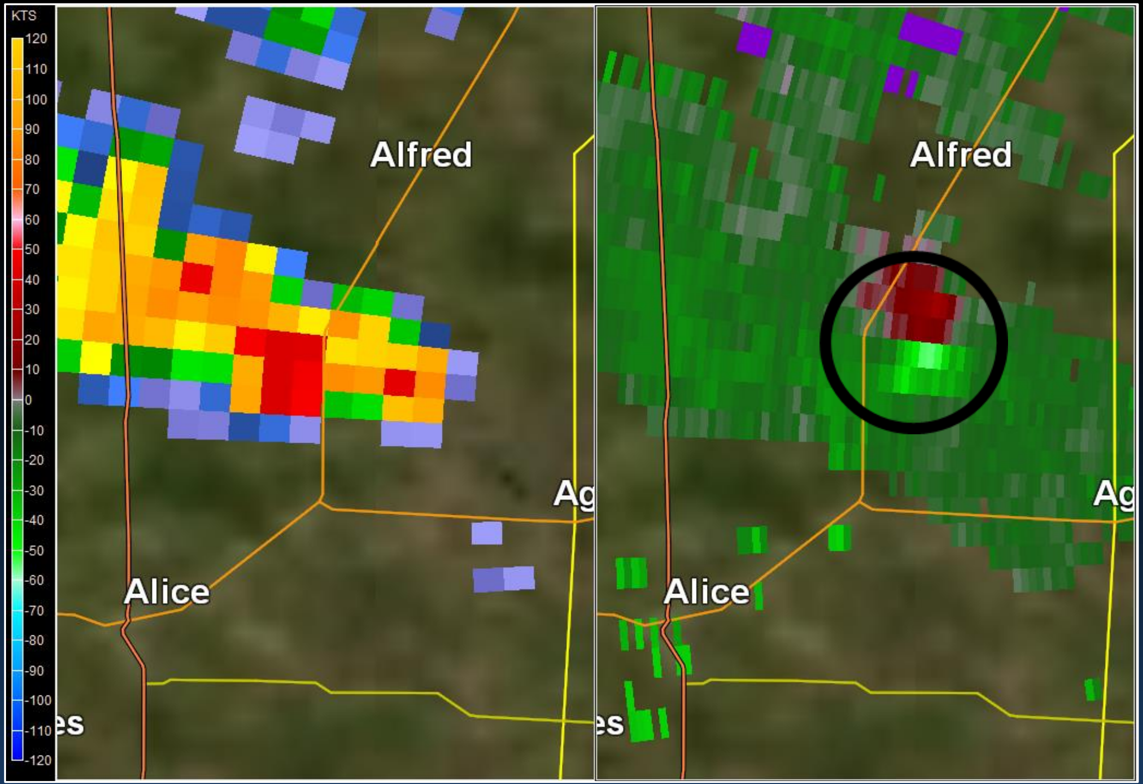




2 of Hurricane Emily’s Tornadoes

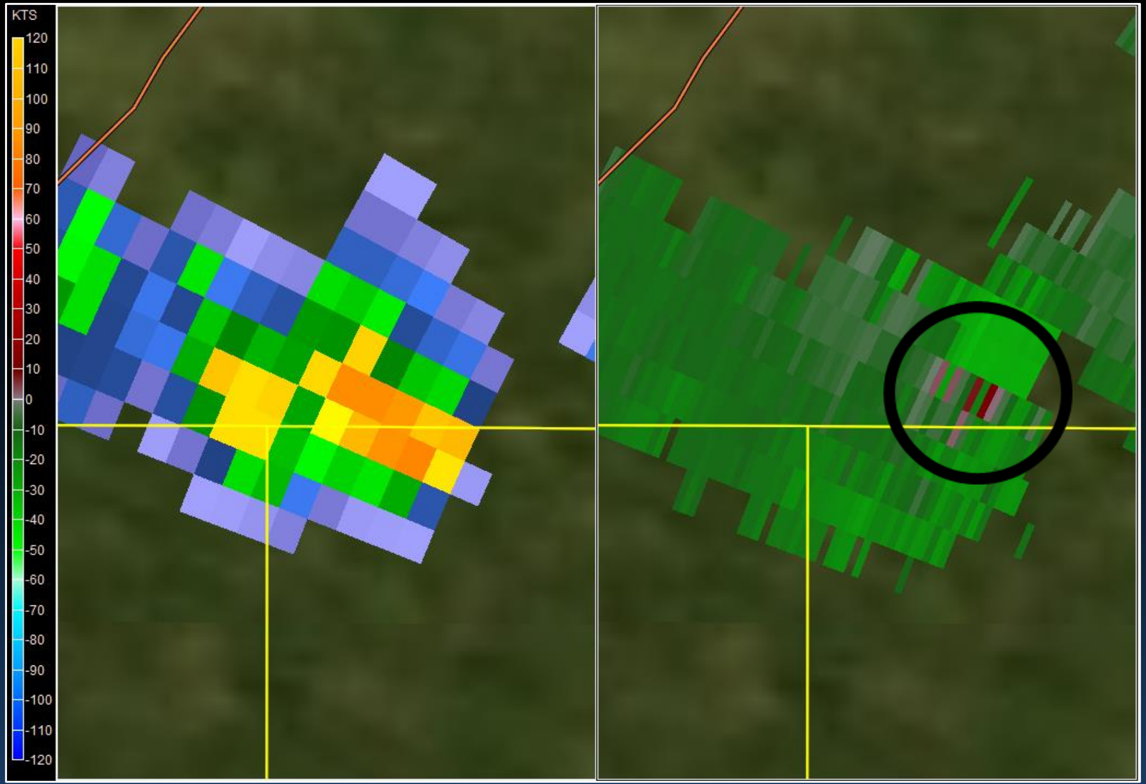
EF-1: 8 miles N of Alice – 1621Z

LLRV ~ 40 kts



EF-0: 3 miles SW of Anna Rose – 1542Z

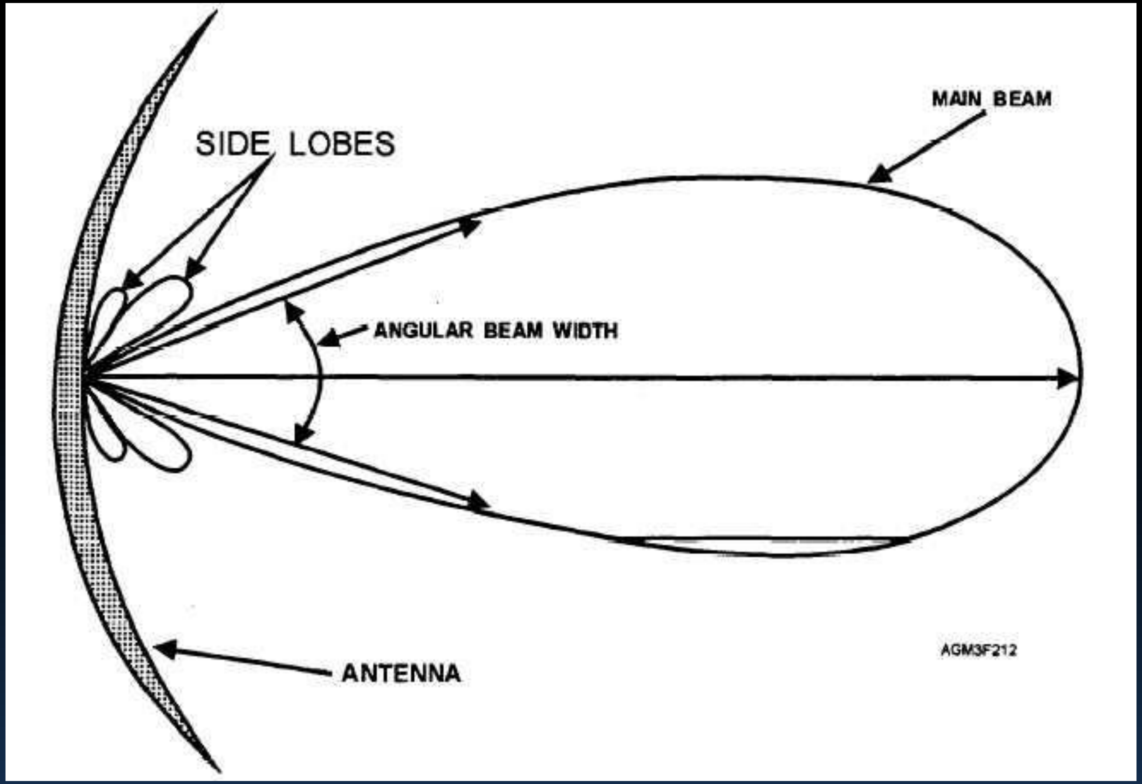
LLRV ~ 22 kts



Side Lobe Contamination

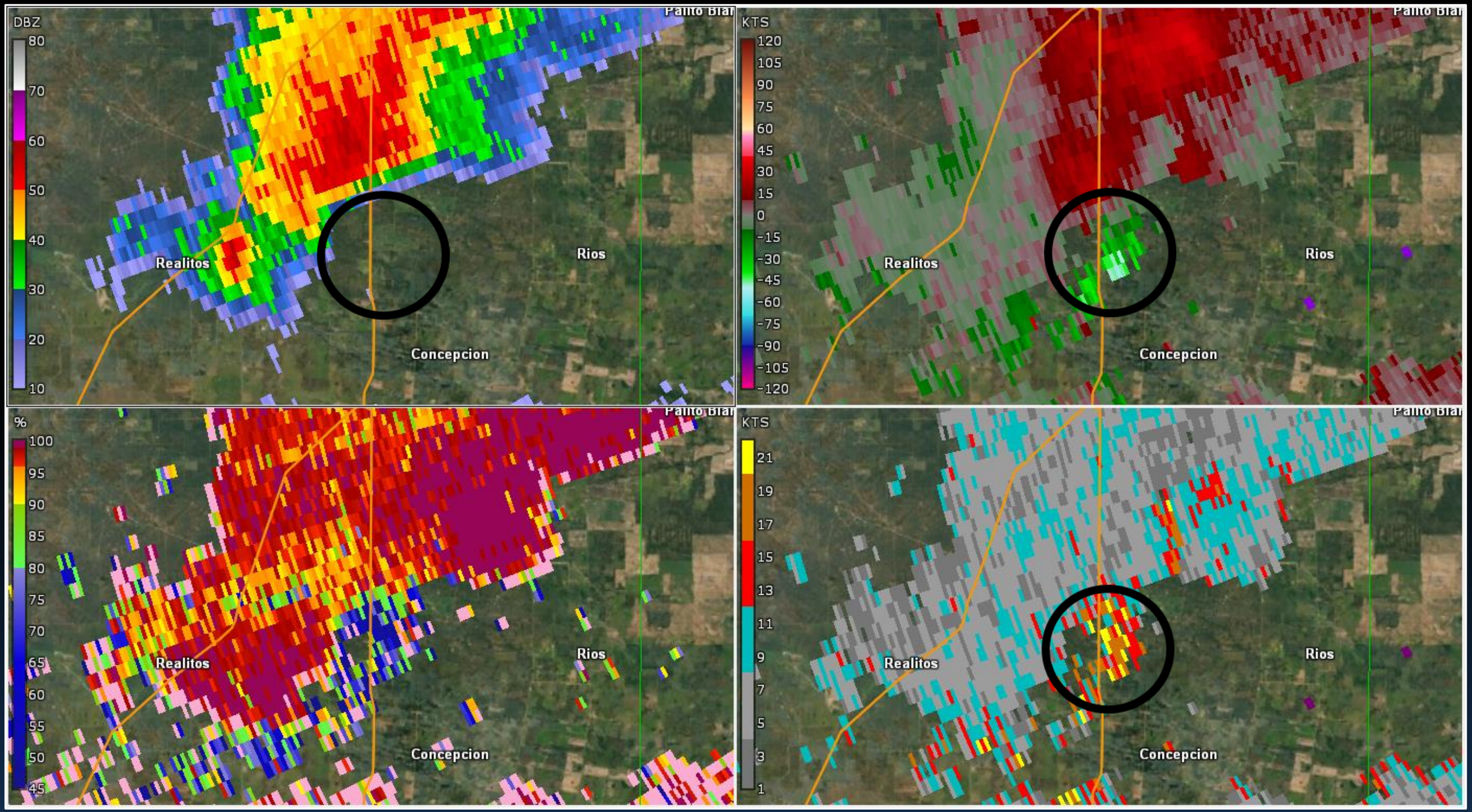
Side Lobe

- Side lobes are small amounts of radiation that emanate from the radar.
- This weak signal is often masked by the returned energy from the main lobe.
- However, there are times when the energy returned from the side lobe can be larger than the main lobe.
- This is called "side lobe contamination".



Side Lobe

- In tilted storms:
  - Side lobe can interact with the higher core aloft.
  - Main lobe can interact with the reflectivity-free area beneath the overhang.
- If the difference exceeds 54 dB, then velocity data from side lobe gets incorrectly mapped to the lower elevation of the main lobe.



Side Lobe

- False low level couplet, displaced by several miles to the SE of the low level reflectivity.

- Spectrum width values ≥ 16 kts can be helpful in diagnosing.

- Low CC values and inconsistent ZDR values may also be helpful.

Radar and Forecast Aids Sections: SOO webpage

All Hazards Decision Chart

8

All Hazards Decision Chart

Tornado

Mesocyclonic

Near Storm Environment: Effective Bulk Wind Difference (EBWD) > 40 kt, effective SRH >150 m^2s^{-2}, MLLCL < 1000 m, MLCAPE > 1500 J/kg, MLCIN < 50 J/kg within last hour

Storm Characteristics: Supercell, strengthening updraft, acceleration & convergence into a strong low-level meso, TVS. TDS means tornado is likely occurring

Non-mesocyclonic

Near Storm Environment: 0-1 km lapse rate > 9°C/km, 0-3 km MLCAPE > 100 J/kg, MLCIN < 25 J/kg, significant surface vertical vorticity associated with a slow moving wind shear boundary.

Storm Characteristics: Look for strong, rapidly growing updrafts via development of reflectivity core at -10° C, TVS. TDS means tornado is likely occurring

Severe Hail

Near Storm Environment: 0-6 km Bulk Wind Difference (BWD) ≥ 27 kt, MUCAPE ≥ 2000 J/kg, 700-500 mb lapse rate > 8.5°C/km, Depth of hail growth zone (-10° to -30C°) (THK_{HGZ}) ≤ 2700 m, Sfc to Equilibrium Level (EL) Bulk Shear ($Shear_{EL}$) ≥ 58 kt, Direction diff between winds at the EL & in 3-6 km layer (GRW_{dirEL}) ≥ 15°, Direction diff between storm-relative wind in 3-6 km and 0-1 km layers (SRW_{dirMD}) ≥ 90°

Storm Characteristics:

≥ 1": Strong updraft, WER, 50 dBZ thickness above the melting level ≥ 16 kft, Z ≥ 60 dBZ, CC = 0.93-0.97, storm-top divergence (STD) ΔV > 70-102 kt, TBSS, MESH ≥ 1"

>2": Supercell, BWER, updraft lasts > 10 min, 60 dBZ above -20°C, 50 dBZ above the EL, CC = 0.7-0.9, ZDR ≈ 0 dB, STD ΔV > 130-162 kt, MESH ≥ 2"

>4": Updraft lasts > 20 min, STD ΔV > 233-267 kt

Severe Wind

Individual Cell Downbursts

Near Storm Environment: Wet Microburst: 0-3 km max $\Delta\theta_e$ > 25°C, DCAPE > 1250 J/kg, SBCAPE > 1000 J/kg, 0-3 km lapse rate > 7°C/km, MLLCL > 1000 Dry Microburst: Inverted-V sounding (midlevel based), MUCAPE > 0 J/kg, MLLCL height > melting level, weak 0-6 km shear, weak boundary layer winds, 0-3 km lapse rates ~ dry or superadiabatic

Storm Characteristics: Strong elevated precip core rapidly forms, descending core bottom, MARC (0°C to LCL) ΔV > 15 kt, wet hail signature (TBSS, CC ~ 0.93-0.96, KDP > 3°C/km), low-level V > 30 kt within 20 nm of radar, fast storm motion *Note: Beware of low Z cells w/high LCLs at 0°C and/or strong wind in mixing layer.*

Rear Flank Downdraft (RFD)

Near Storm Environment: 0-6 km shear ≥ 30 kt, low LCL, large CAPE, steep sub-cloud adiabatic lapse rate

Storm Characteristics: Meso w/MDA rank 5+ (Vr > 30 kt), developing large hook echo (>50 dBZ), DCZ > 10 kft (> 15-20 kft optimal), fast motion

MCSs/Horizontally-Driven Wind

Near Storm Environment: Widespread lift, DCAPE > 980 J/kg, 0-6 km mean wind > 16 kt, MUCAPE > 2000 J/kg, 0-6 km bulk wind difference > 20 kt

Storm Characteristics: Strong leading Z gradient, bow echo, Rear Inflow Jet (RIJ), MARC ΔV > 50 kts at 3-5 km AGL, Deep Convergence Zone (DCZ) > 10 kft (> 15-20 kft is optimal), gust front speed matches system speed, linear WER along leading edge, fast storm motion

Note: A mesovortex w/RIJ produces strongest wind.

Flash Flood

Individual Cell

Near Storm Environment: High PW & RH (>70%) in convective layer, warm cloud layer > 10 kft, weak convective-layer wind < 10 kt

Storm Characteristics: Slow motion < 10 kt, Z > 50-60 dBZ (45-55 dBZ trop. env.), low echo centroid, CC > 0.96, ZDR = 2-5 dB (0.5-3.0 dB trop. env.), KDP > 1°/km

Multicell

Near Storm Environment: High PW & RH (>70%) in convective layer, LLJ transporting high moisture, slow MBE motion, slow (< 15 kt) motion of forcing mechanism, upwind instability

Storm Characteristics: Intra-storm seeding; collisions; slow motion; training / backward propagation < 15 kt; leading, parallel, or adjoining stratiform MCS

Antecedent Ground Conditions

Poor permeability (urban land use, clay soil, rock, ice, desert pavement, burn scars, etc.), poor drainage, saturated soil (recent rain, snowmelt, etc.), sloping terrain (mtns, canyons, hills, etc.)

Precipitation Accumulation

Does rainfall meet flash flood thresholds?

1. Pick your optimal precip source: Dual-Pol, legacy DHR, HPE, Bias HPE, MRMS
   a. Assess radar QPE biases
   b. Compare QPE with observations
2. Use FFMP for decision making
   a. Ratio > 100%, diff > 0"
   b. Look at 1-, 3-, and 6-hour durations
3. Is additional rainfall occurring or imminent?

Version FY17.1

Using Radar to Estimate Hail Size

10

Radar Estimated Hail Type/Size

Storm-Top Divergence

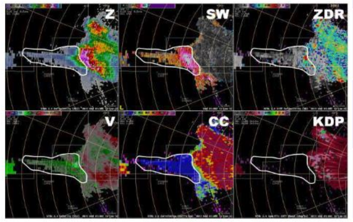
Peak ΔV(kts)	Max Hail Size (in.)
70-102	Quarter (1")
103-134	Ping Pong (1 ½")
115-147	Golf ball (1 ¾")
130-162	Hen Egg/Lime (2")
159-192	Tennis Ball (2 ½")
174-207	Baseball (2 ¾")
233-267	Grapefruit (4")

DUAL-POL RADAR HAIL SIGNATURES

Z: 45-59 dBZ = Hail poss ≥60 dBZ = Hail likely	**ZDR**: -0.3 to 1 dB ≈ Dry or large hail > 1 dB ≈ More liquid
CC: 0.93 - 0.97 ≈ 1-2" hail 0.70 - 0.90 ≈ ≥2" hail	**KDP**: <1°/km ≈ Mostly dry hail >3°/km ≈ Rain/hail combo or melting hail

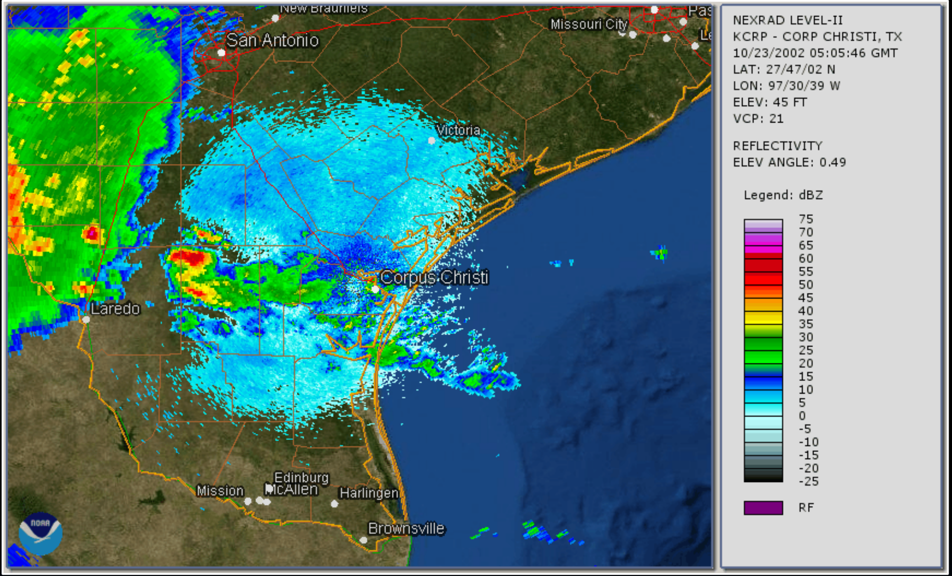
Hail Event Type	Signature	
Severe Hail (with little rain)	Z > 55 dBZ	ZDR < 1 dB
	CC ≈ 0.95-0.97	KDP < 1°/km
Severe Hail Mixed w/Rain	Z > 55 dBZ	ZDR ≈ 1-2 dB
	CC ~0.93-0.96	KDP > 0.5°/km
Sub-Severe Dry Hail	Z ≈ 45-55 dBZ	ZDR ≈ 0 dB
	CC > 0.98	KDP ≈ 0°/km
Sub-Severe Melting Hail	Z > 55 dBZ	ZDR > 2 dB
	CC ≈ 0.92-0.96	KDP > 4-5°/km
Significant (≥2") Hail	Z > 55 dBZ (>45 dBZ)	ZDR ≈ 0 dB or lower
	CC < 0.9 (possibly 0.7)	KDP not displayed

TBSS ≥ 0.8" Hail*



*Valid for S-band radar only

The End



San Antonio
Missouri City
Victoria
Corpus Christi
Laredo
Mission
Edinburg
McAllen
Harlingen
Brownsville
NEXRAD LEVEL-II
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LON: 97/30/39 W
ELEV: 45 FT
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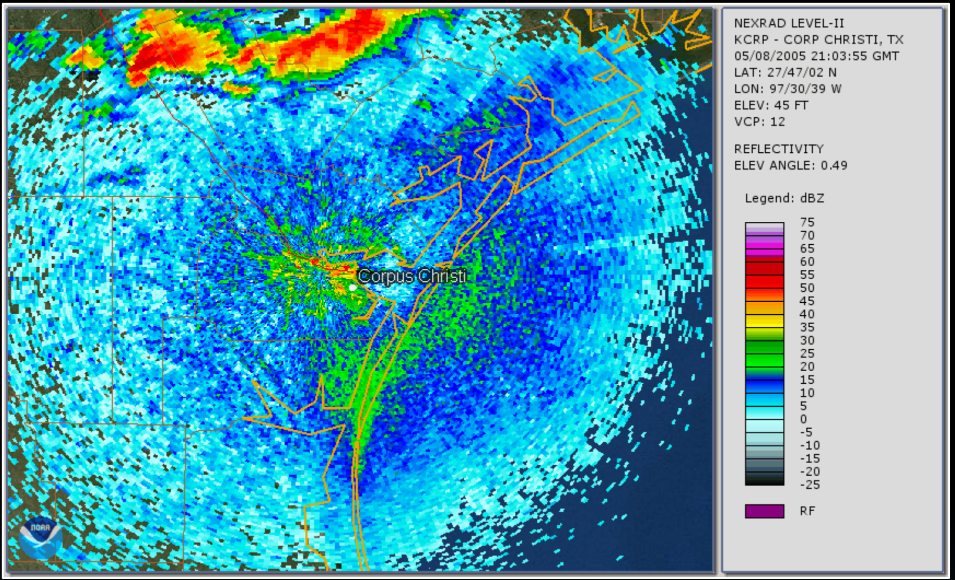
RF



Corpus Christi
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LON: 97/30/39 W
ELEV: 45 FT
VCP: 12
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ELEV ANGLE: 0.49
Legend: dBZ
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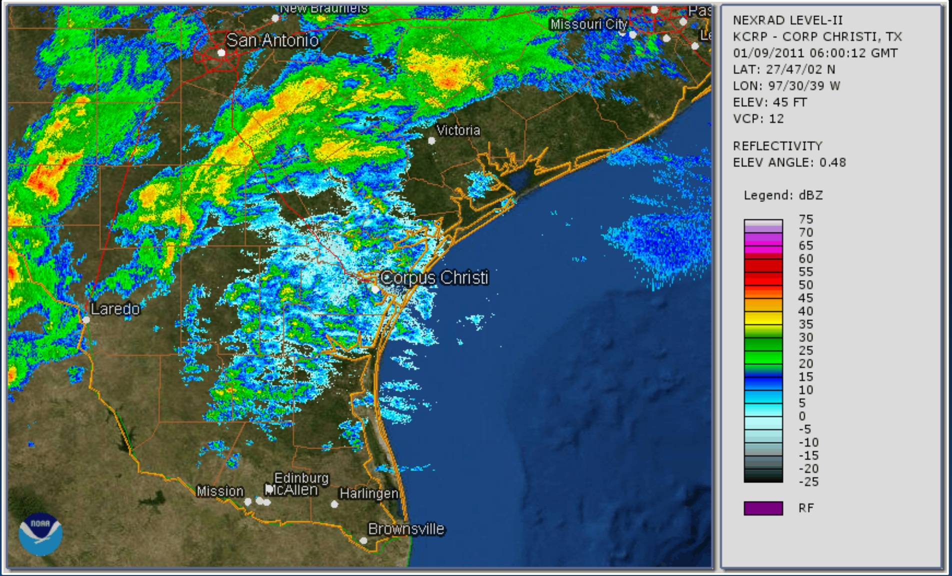

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Brownsville
NEXRAD LEVEL-II
KCRP - CORP CHRISTI, TX
01/09/2011 06:00:12 GMT
LAT: 27/47/02 N
LON: 97/30/39 W
ELEV: 45 FT
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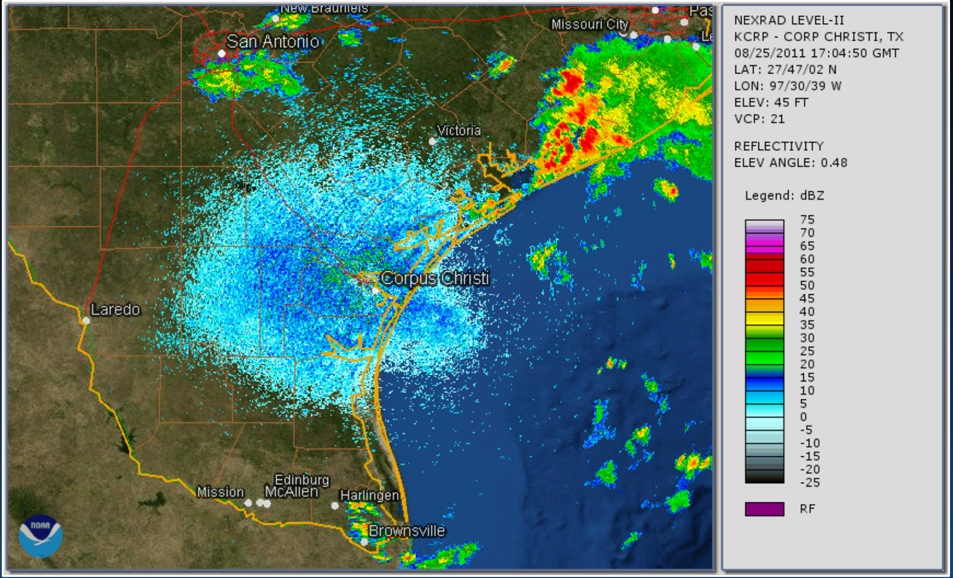

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08/25/2011 17:04:50 GMT
LAT: 27/47/02 N
LON: 97/30/39 W
ELEV: 45 FT
VCP: 21
REFLECTIVITY
ELEV ANGLE: 0.48
Legend: dBZ
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RF