

RAPID-SCAN, POLARIMETRIC, MOBILE DOPPLER RADAR OBSERVATIONS
OF AN EF-5 TORNADO

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Hurricane Research Division/NOAA
13 March 2012 Miami, FL

SW of El Reno, OK
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SCIENTIFIC GOALS: UNDERSTAND **TORNADOGENESIS** IN SUPERCELLS AND **TORNADO STRUCTURE**

RAPID-SCAN DOPPLER RADARS APPLIED TO STUDY OF SEVERE CONVECTIVE STORMS

- ADVECTIVE TIME SCALE OF TORNADOES ~ 10 s (OR LESS): MOST MOBILE RADARS AND WSR-88D RADARS HAVE VOLUME UPDATES TIMES $\sim$ MIN
- TRACK REFLECTIVITY ELEMENTS AND USE INFO. IN CONJUNCTION WITH DOPPLER WIND VELOCITIES TO SYNTHESIZE 3D WIND FIELD
- PURPOSE OF TALK: SHOW DATA OF EF-5 TORNADO FROM POLARIMETRIC MOBILE DOPPLER RADAR IN CENTRAL OKLAHOMA ON 24 MAY 2011
- (• SHOW DATA FROM LARGE HAILSTORM IN SW OKLAHOMA ON 23 MAY 2011 AND ANOTHER TORNADO IN CENTRAL OKLAHOMA ON 24 MAY 2011)
- (• SHOW SOME DATA COLLECTED DURING YEAR 2 OF VORTEX2 AND ACCOUNTS OF A FEW OTHER “EXPEDITIONS”)

Meteorological **W**eather **R**adar, 2005, **X**-band, **P**hased Array (MWR-05XP)



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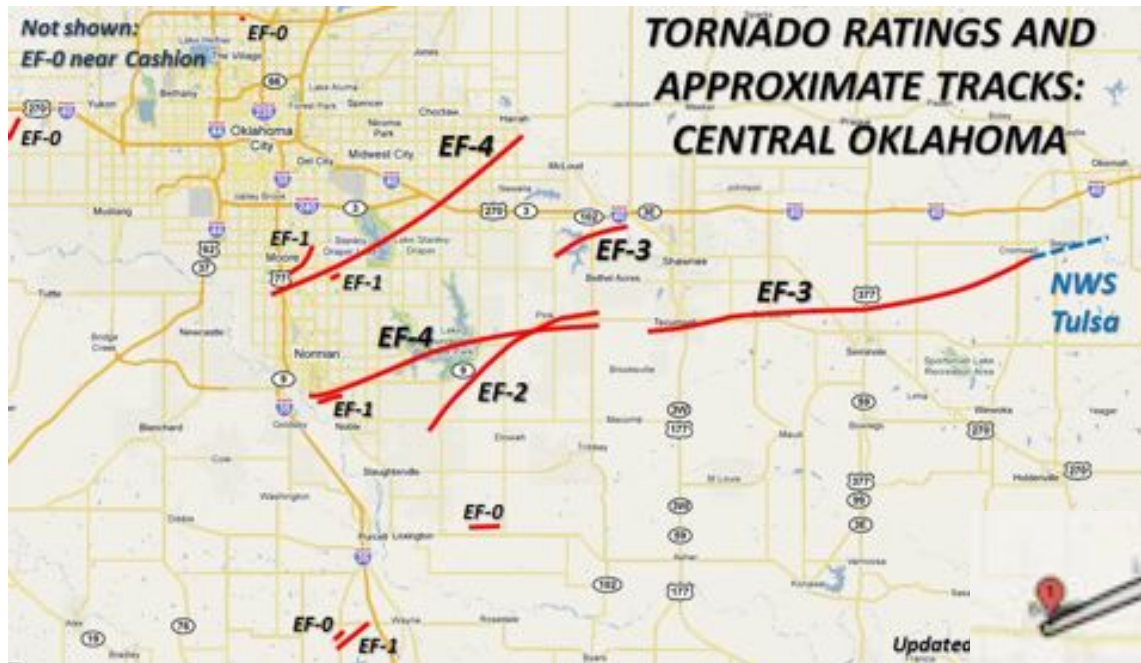
MWR-05XP (FIRST USED IN 2007)

- ELECTRONIC SCAN IN ELEVATION BY CHANGING PHASE DELAY
- ELECTRONIC SCAN IN AZIMUTH BY CHANGING FREQUENCY (“FREQUENCY HOPPING”)
- RATE OF ELECTRONIC BACK SCAN IS EQUAL AND OPPOSITE TO RATE OF RAPID MECHANICAL SCAN: BEAM $\approx$ STATIONARY, SO ENOUGH SAMPLES CAN BE OBTAINED TO ESTIMATE DOPPLER VELOCITY WITH ACCEPTABLE ACCURACY
- “FREQUENCY HOPPING” *BOTH* ELIMINATES AZIMUTHAL BEAM SMEARING *AND* INCREASES THE NUMBER OF INDEPENDENT SAMPLES
- $\sim 2^\circ$ HALF-POWER BEAMWIDTH (LOWER SPATIAL RESOLUTION, BUT VERY FAST)
- SCAN FULL VOLUME OF STORM EVERY ~ 6 -7 SECONDS

SUMMARY OF MOST SIGNIFICANT FINDINGS WITH MWR-05XP (MIKE FRENCH):

HOG BACK TORNADO (23 MAY 2008), GOSHEN COUNTY TORNADO (5 JUNE 2009),
KINGISHER TORNADO (19 MAY 2010, DISSIPATION ONLY)

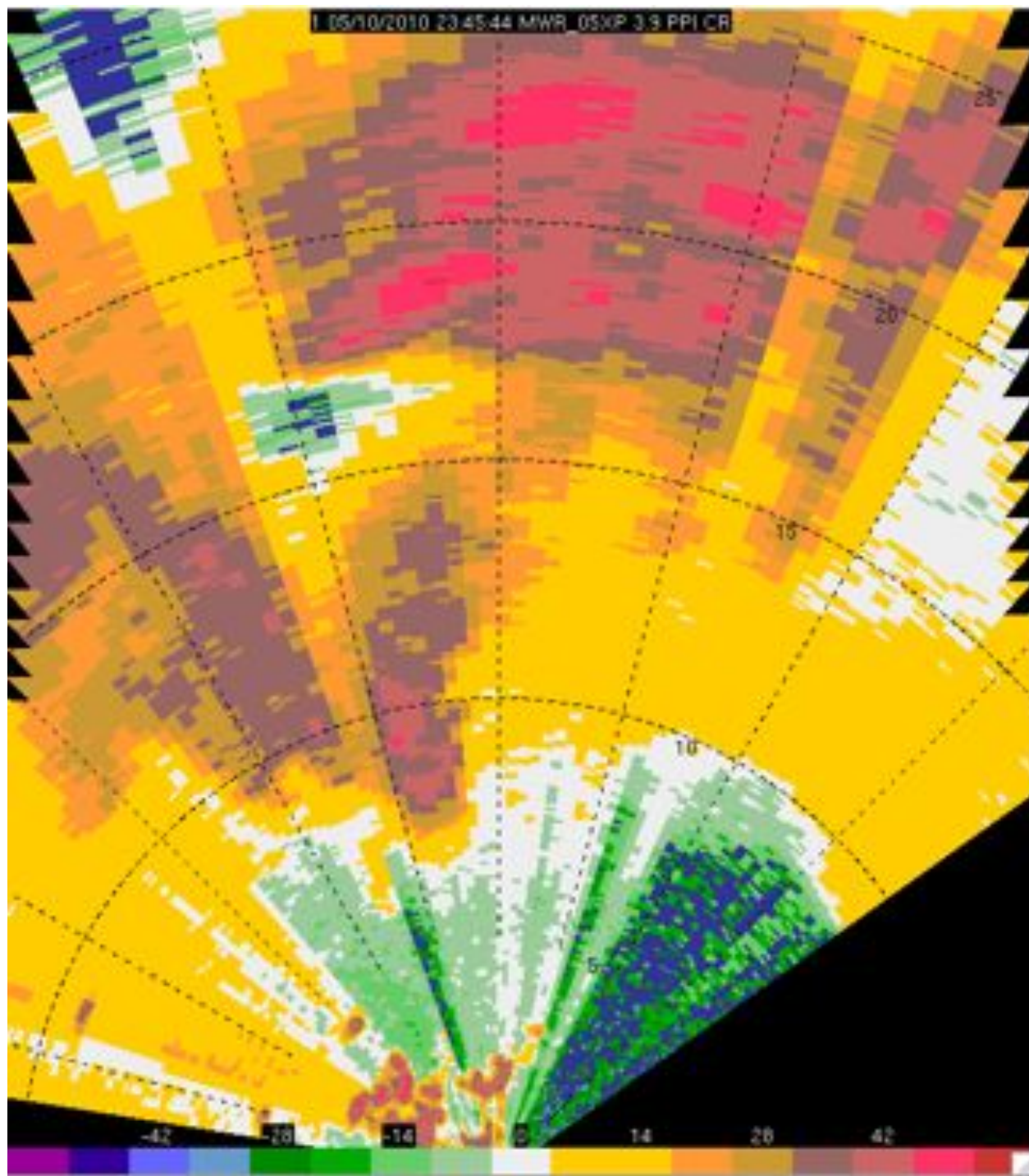
1. TORNADOES BEGIN BELOW AND BUILD **UPWARD** (*TVS DOES NOT DESCEND*)
PRE-RAPID SCAN RADAR RESULTS SHOWING DESCENDING TVS RESULT OF POOR
TEMPORAL SAMPLING
2. IN DISSIPATING TORNADOES, TVS DISSIPATES BOTH DOWNWARD AND UPWARD,
PERSISTING ALOFT AND NEAR THE GROUND LONGER

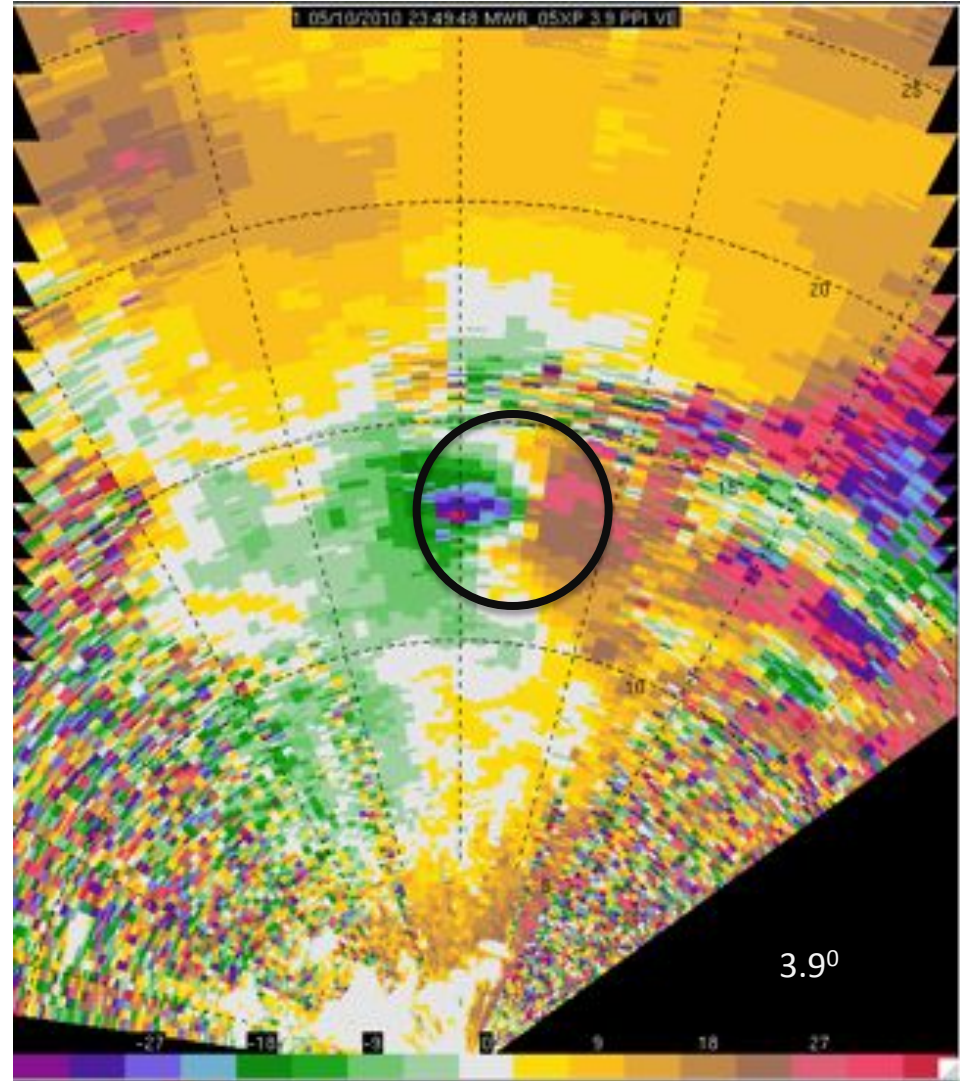
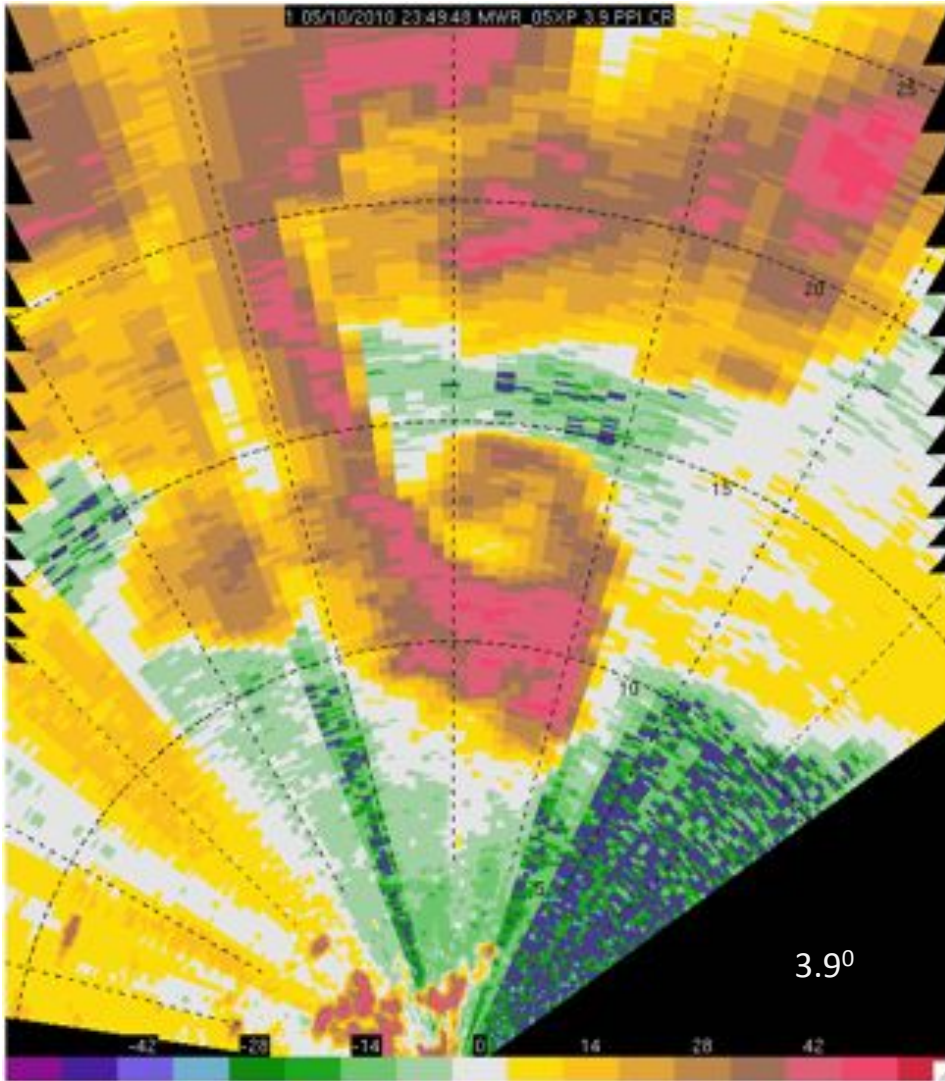


10 MAY 2010 TORNADO OUTBREAK
CENTRAL AND EASTERN OKLAHOMA

EVOLUTION
OF
TORNADO:
REFLECTIVITY
3.9° (TREE
BLOCKAGE
BELOW)
MWR-05XP

10 MAY 2010
EASTERN OK



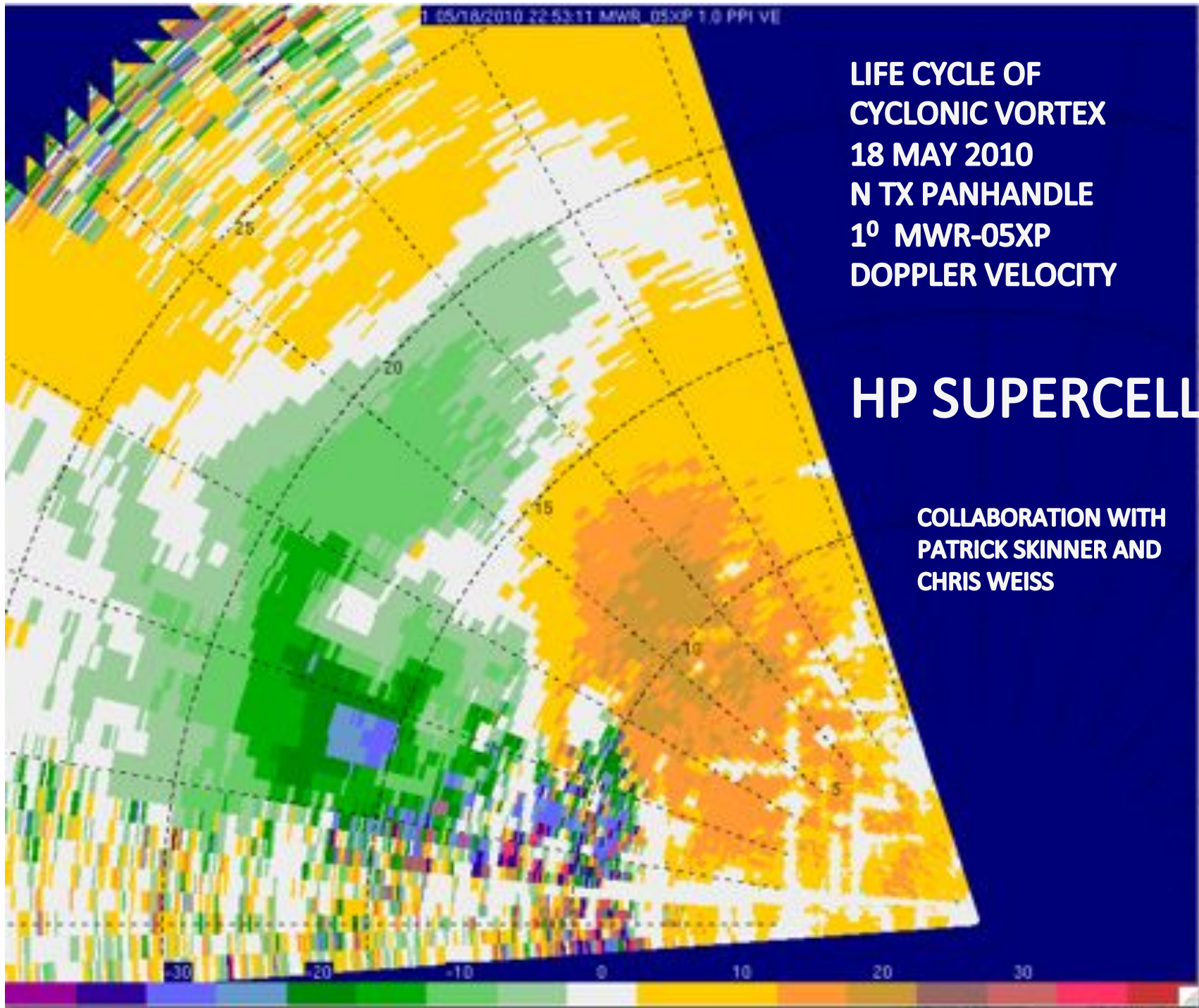


10 MAY 2010
MWR-05XP

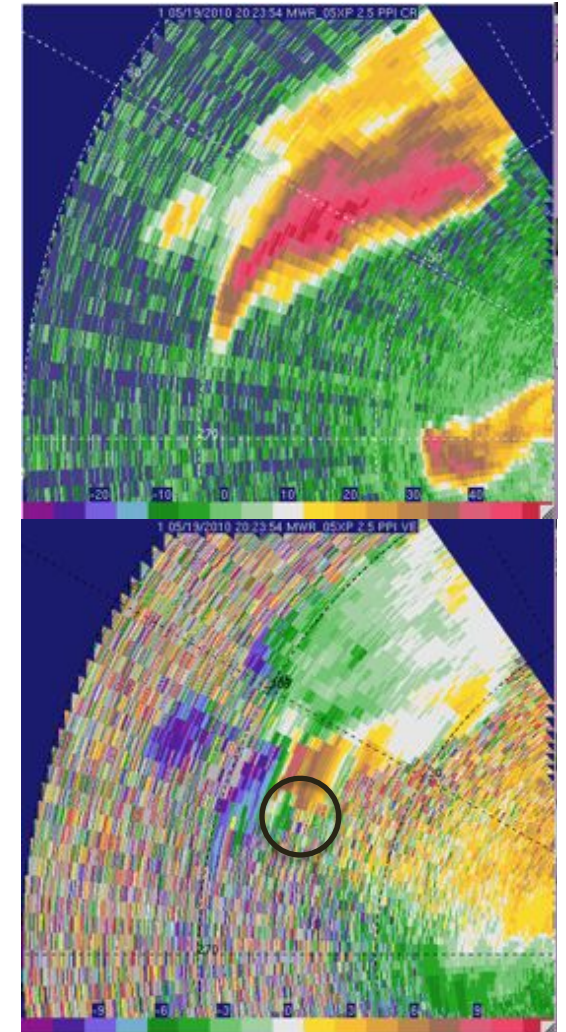
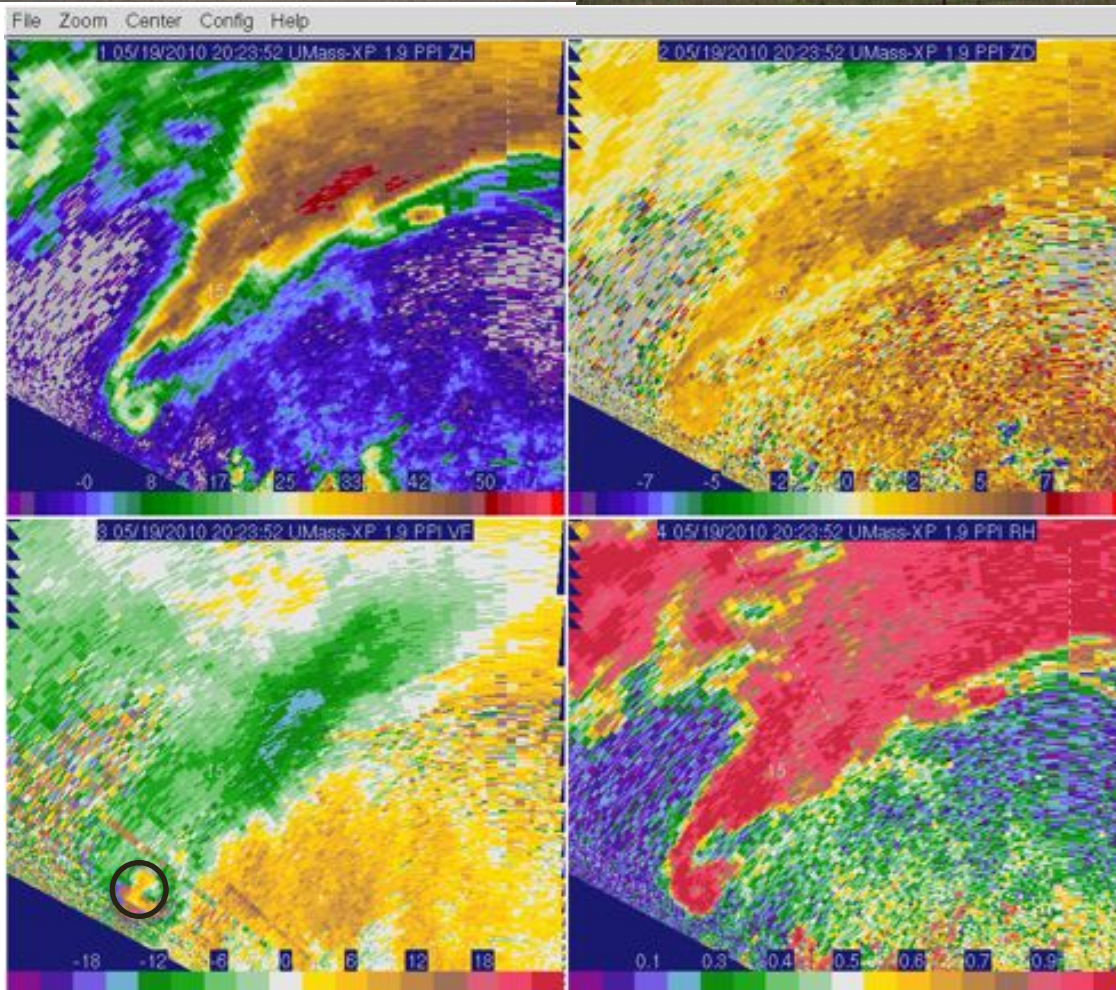
COLLABORATIVE WORK (JEFF SNYDER, MIKE FRENCH)
WITH CHRIS SCHWARZ AND DON BURGESS



18 MAY 2010 NORTHERN TEXAS PANHANDLE © H. Bluestein



- FIRST TORNADO

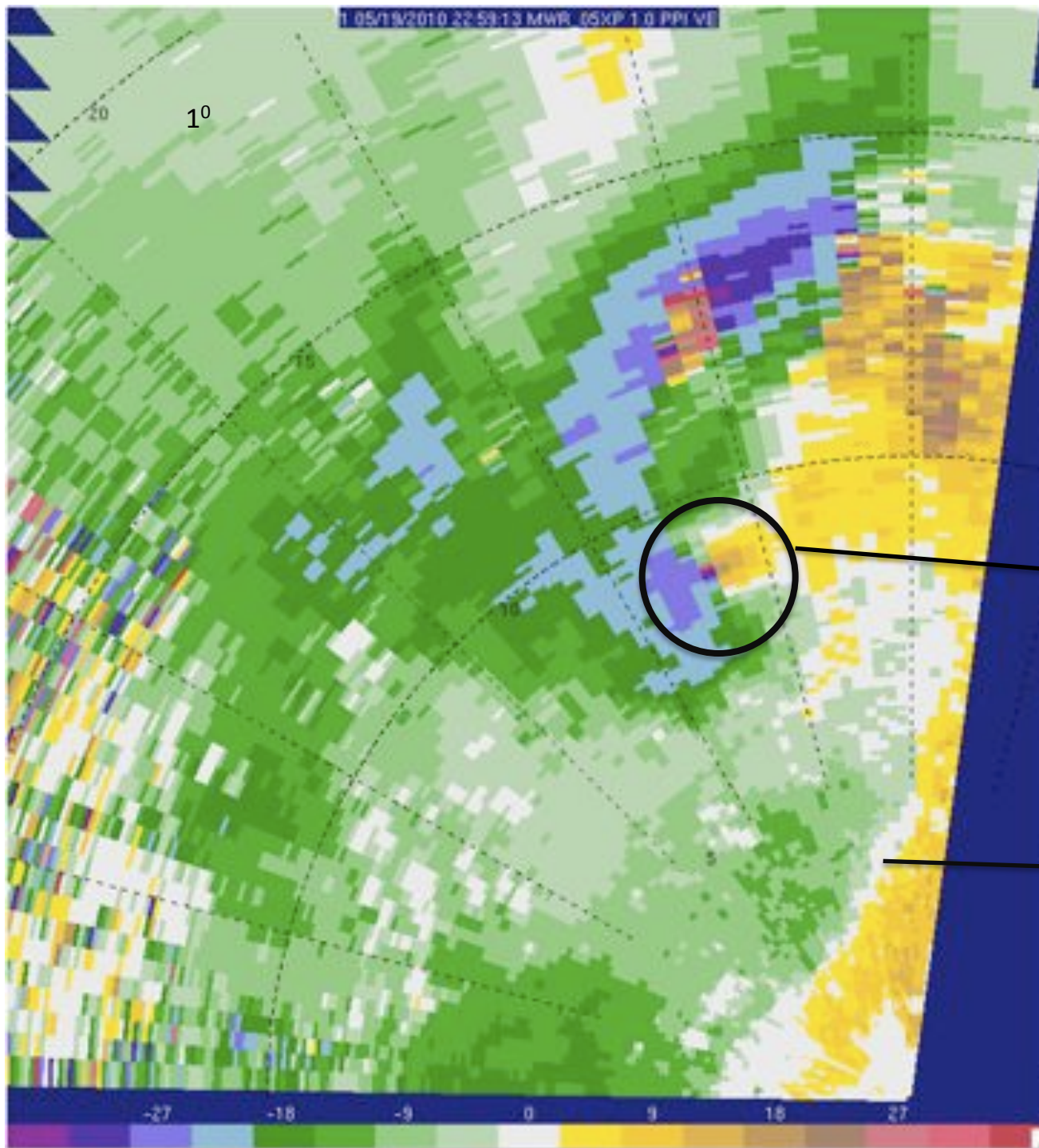


MWR-05XP 2024 UTC

UMASS X-POL
19 MAY 2010 2024 UTC
WESTERN OK



19 May 2010 WESTERN OKLAHOMA © H. Bluestein



• END OF 2nd
TORNADO

MWR-05XP
DOPPLER VEL.

19 MAY 2010

TORNADO

RFD
GUST FRONT



TWIN TORNADOES
(WESTERN KANSAS)
ROTATING AROUND
EACH OTHER
25 MAY 2010:
VERY RAPID EVOLUTION
NO DATA COLLECTION

© H. Bluestein

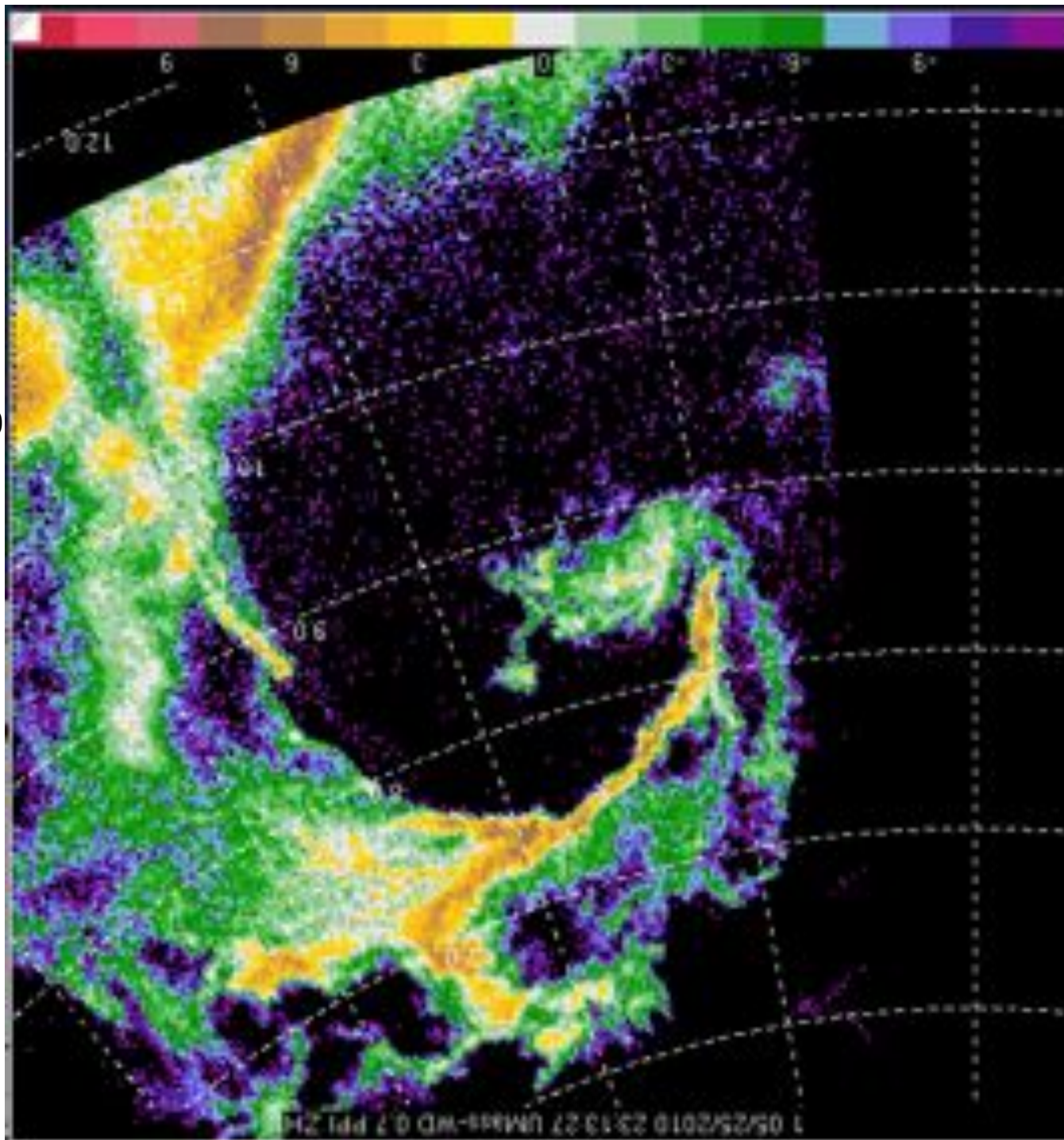


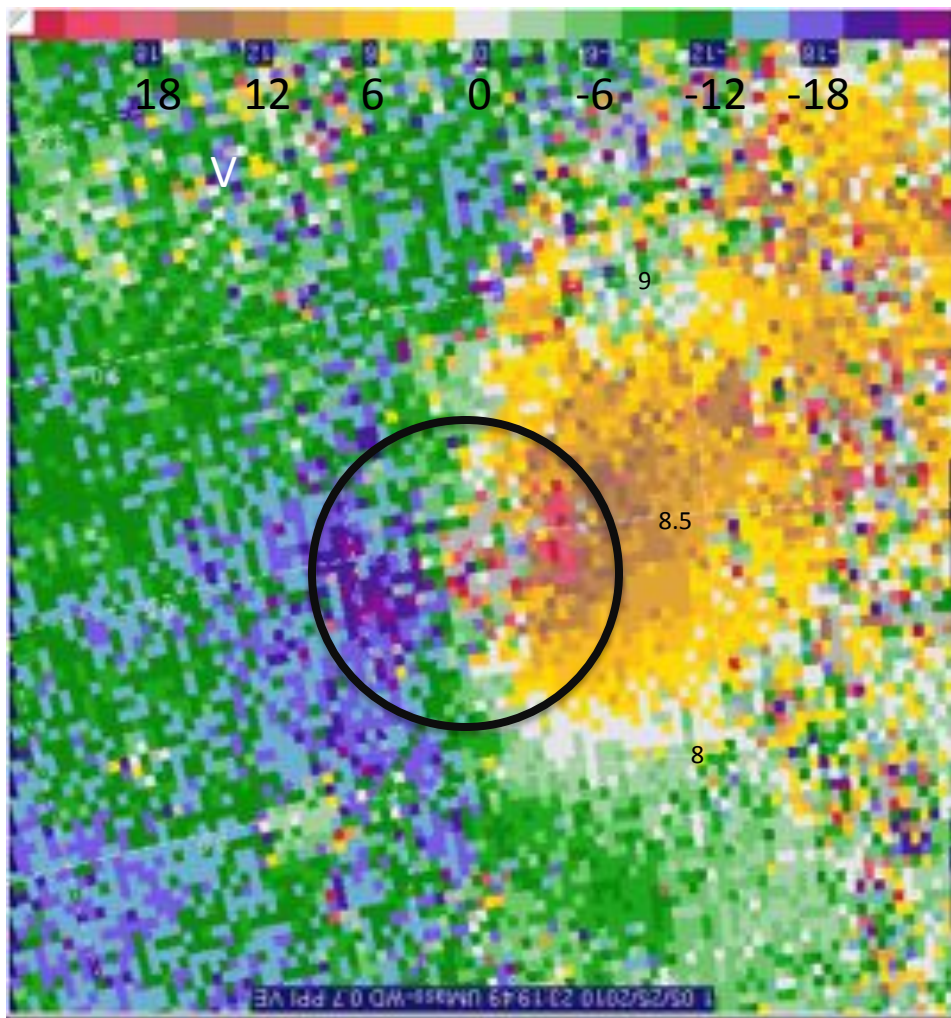
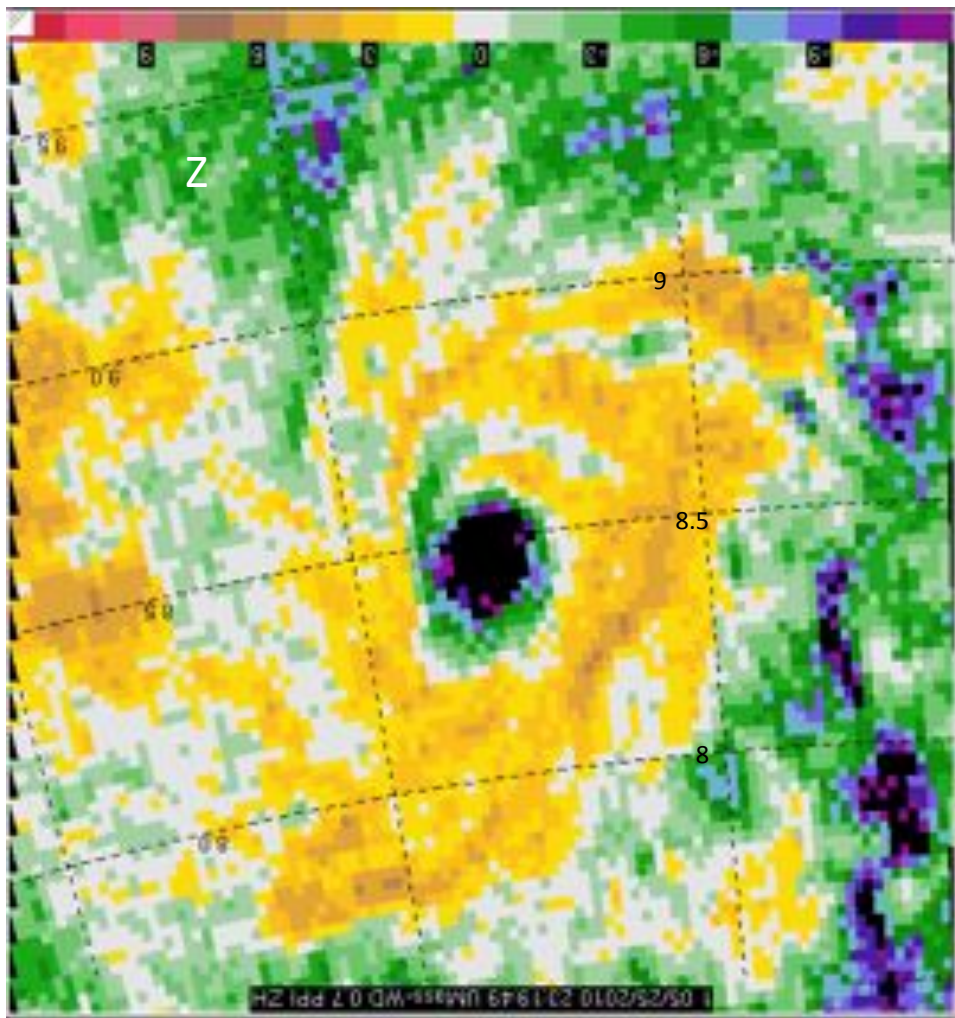


25 May 2010 COLORADO-KANSAS BORDER © H. Bluestein

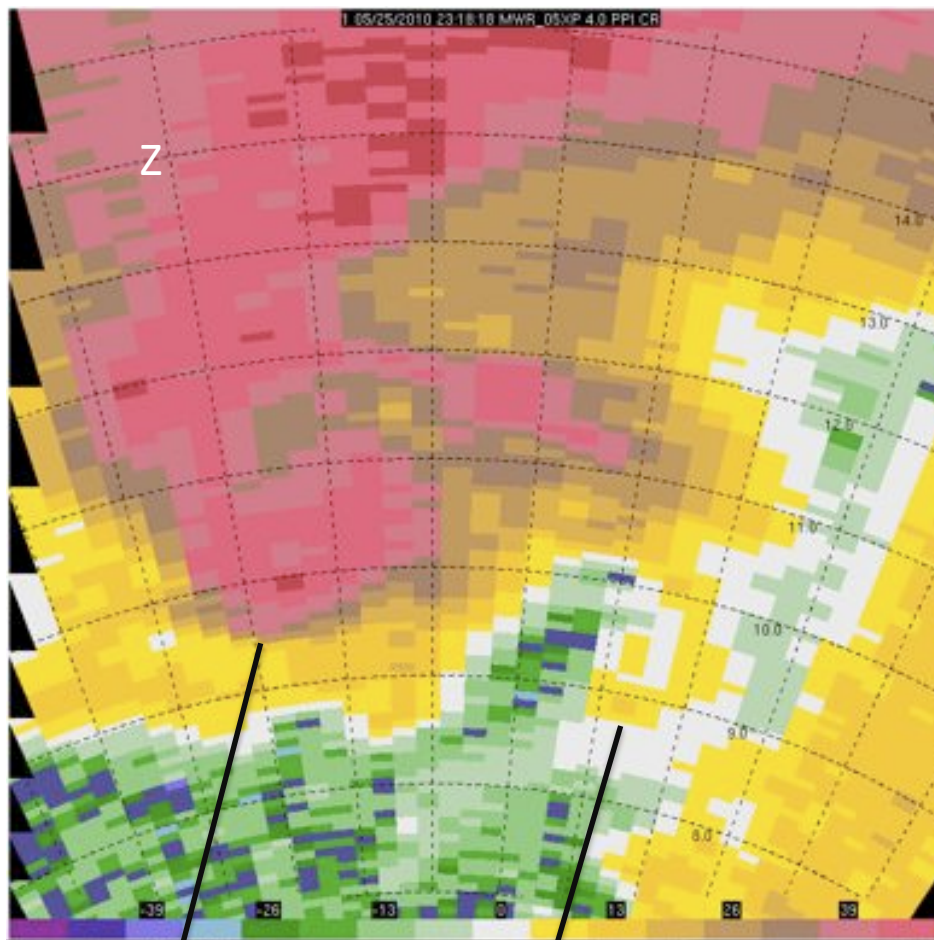
LIFE CYCLE
OF
TORNADO
ON
25 MAY 2010

U MASS
W-BAND
RADAR



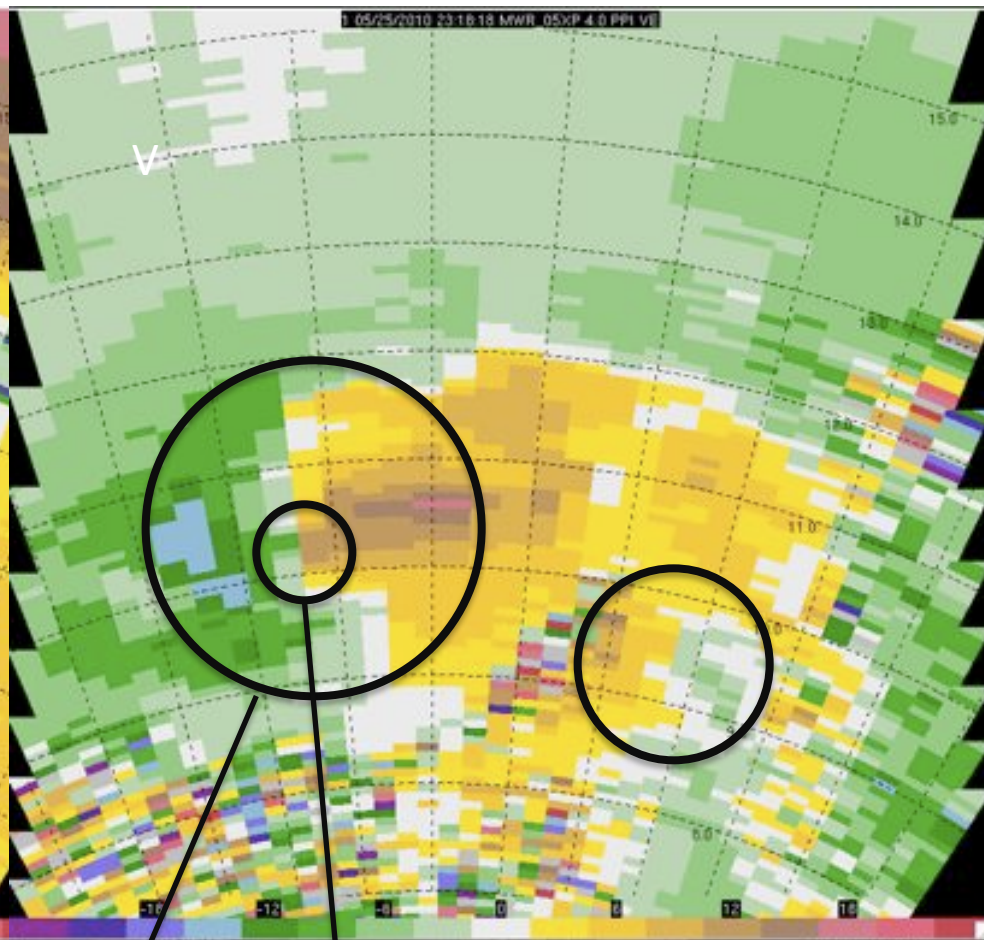


2319:49 UTC 25 May 2010
UMass W-band radar
0.18° beam



CYCLONIC HOOK

ANTICYCLONIC HOOK



MESOCYCLONE

TORNADO?

MWR-05XP DATA
2318:18 UTC 25 MAY 2010

1 05/26/2010 22:33:09 UMass-WD 1.9 PPI ZH

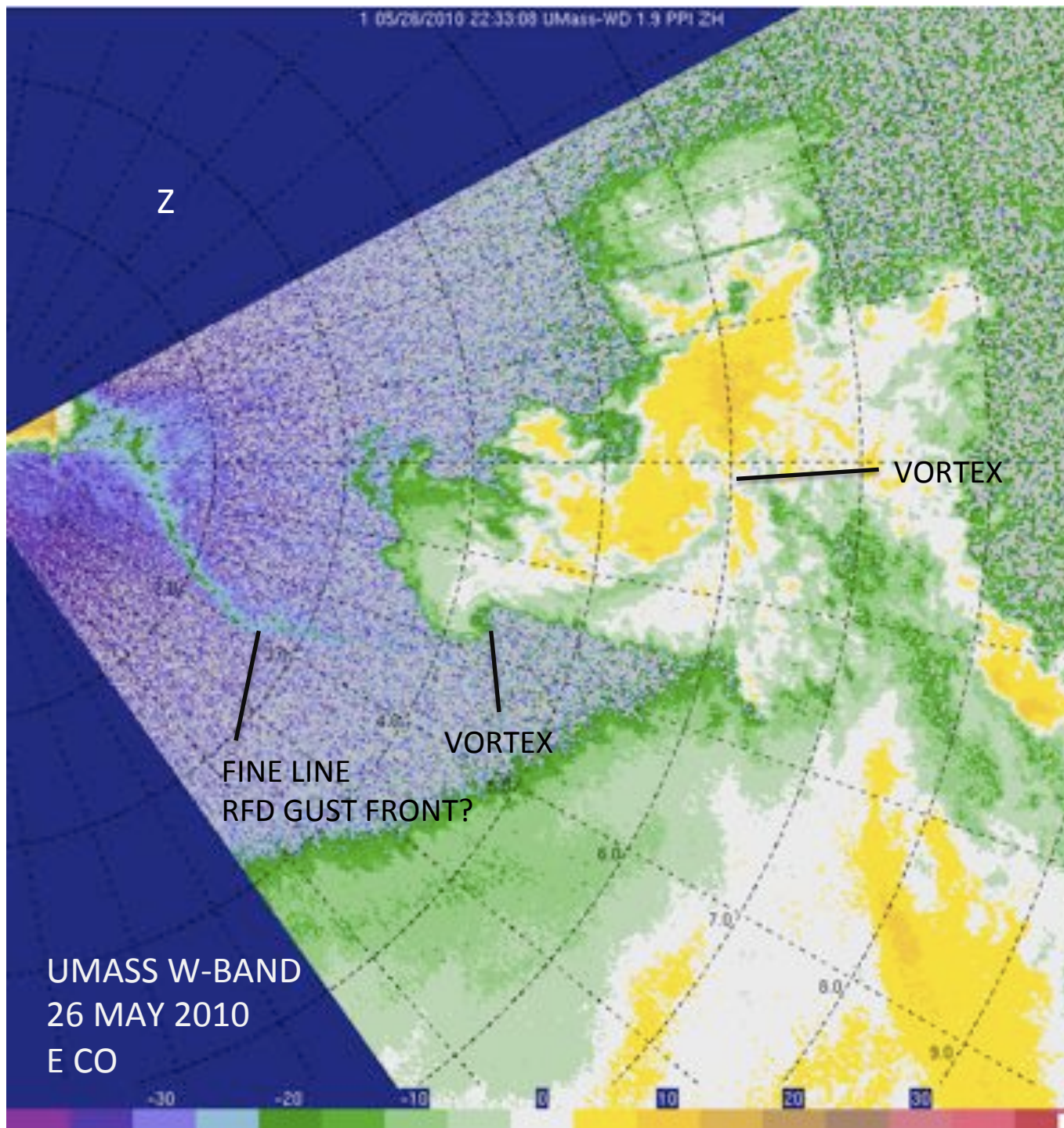
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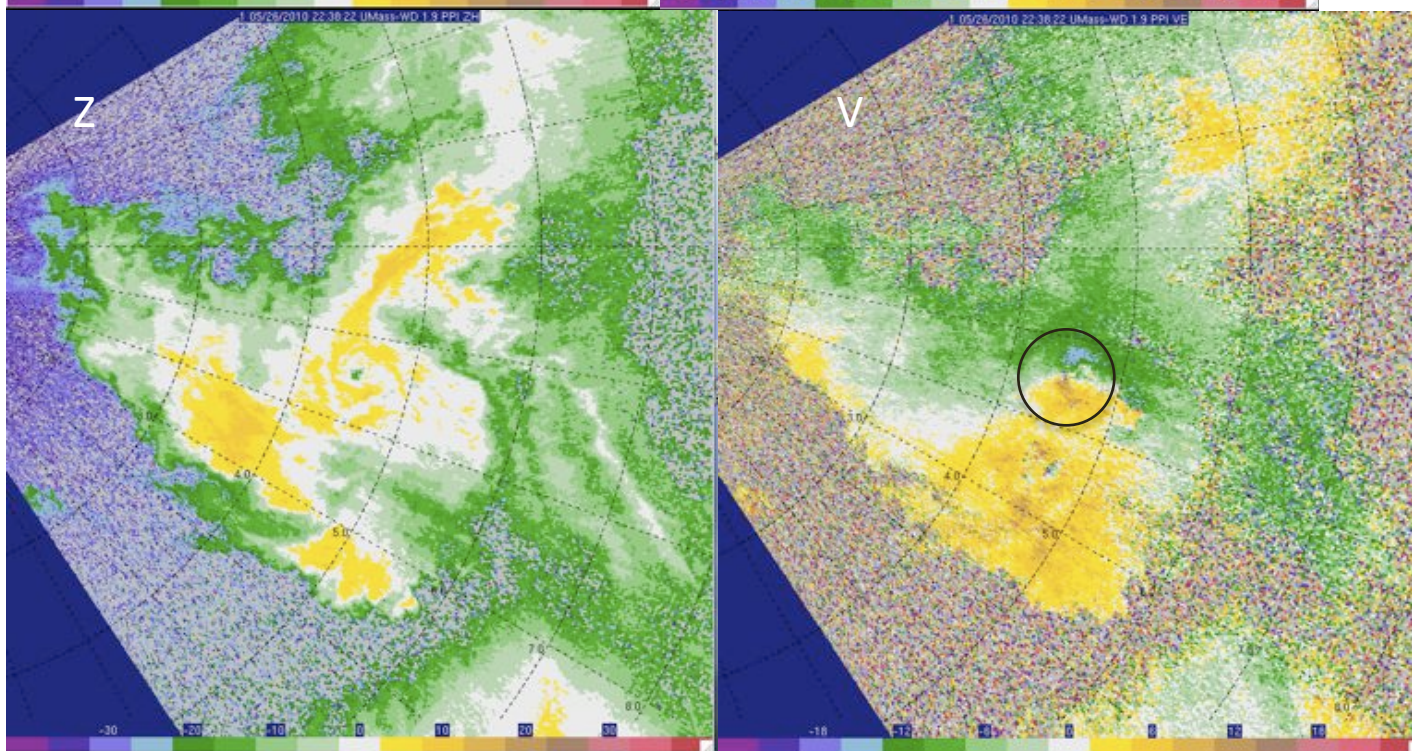
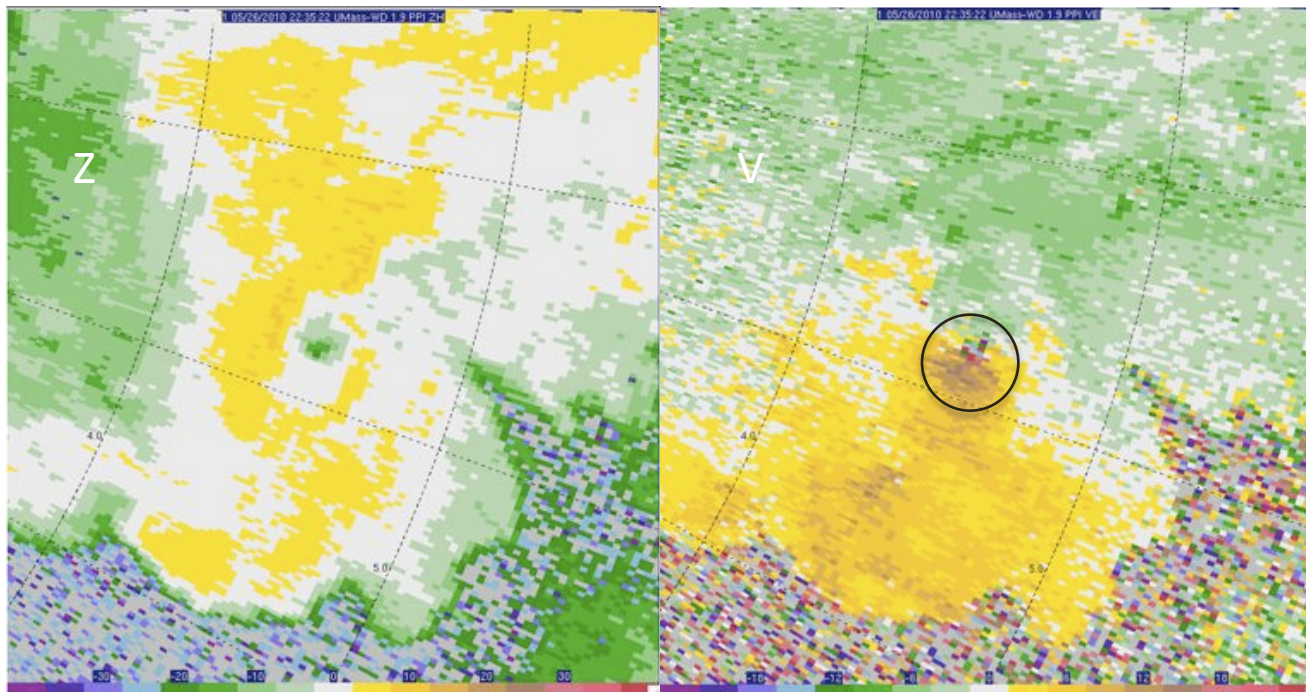
VORTEX

VORTEX

FINE LINE
RFD GUST FRONT?

UMASS W-BAND
26 MAY 2010
E CO



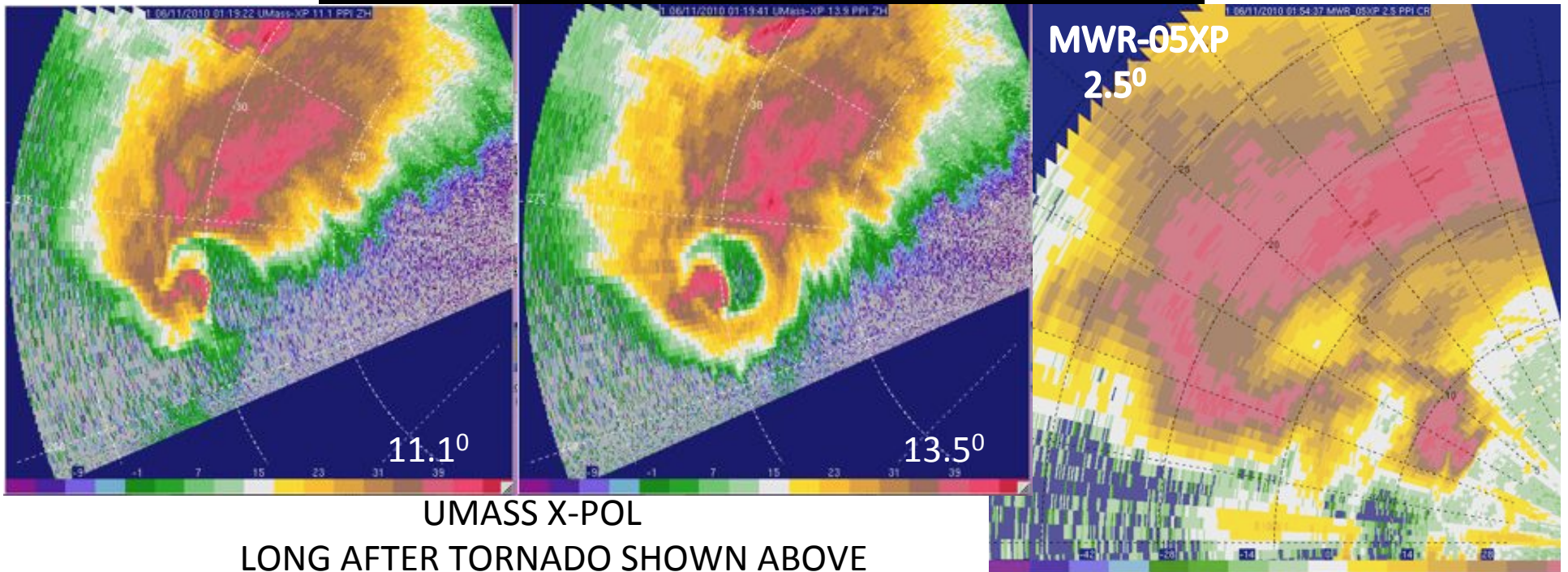


26 MAY 2010
UMASS W-BAND
E CO

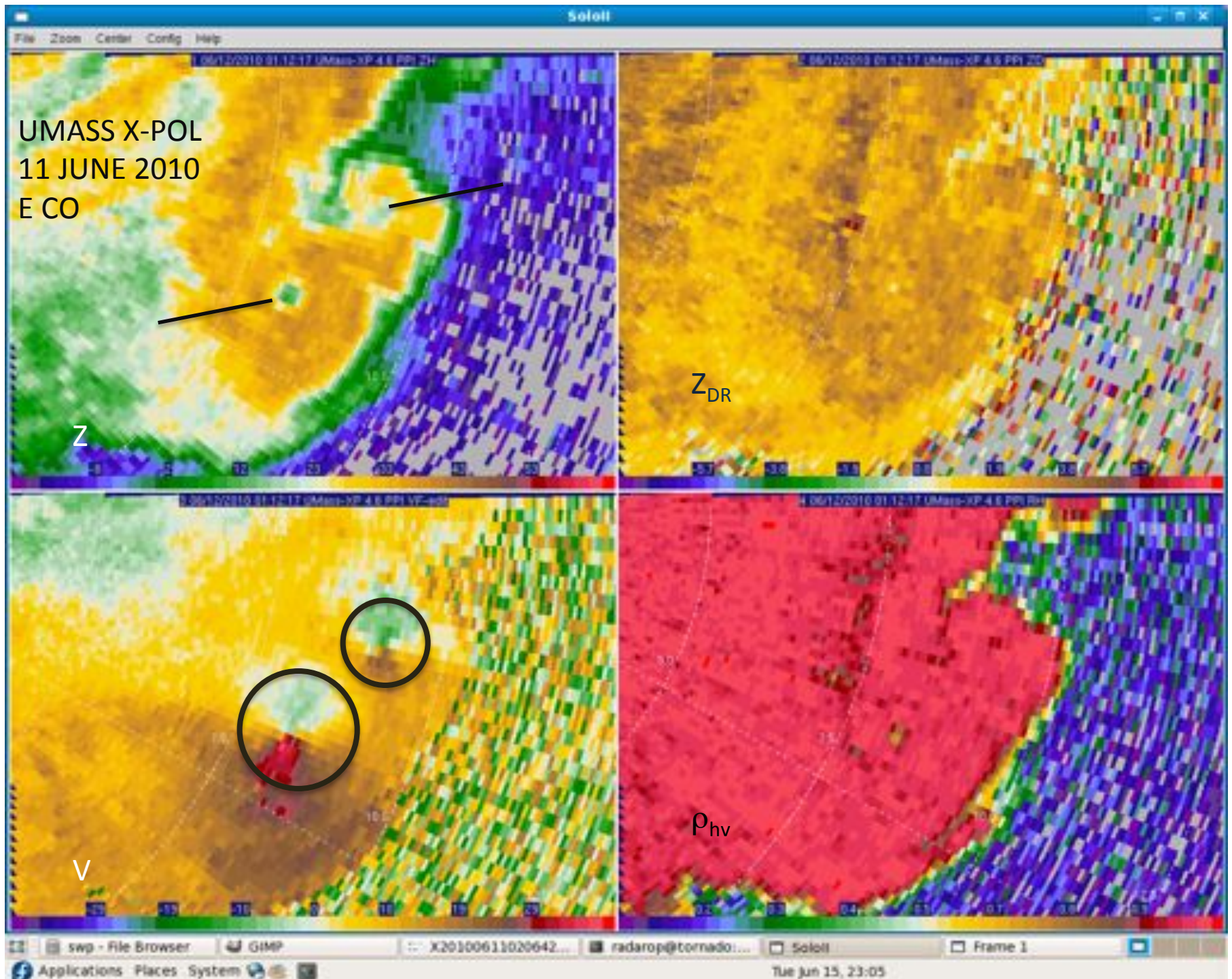


10 JUNE 2010
E CO

© H. Bluestein

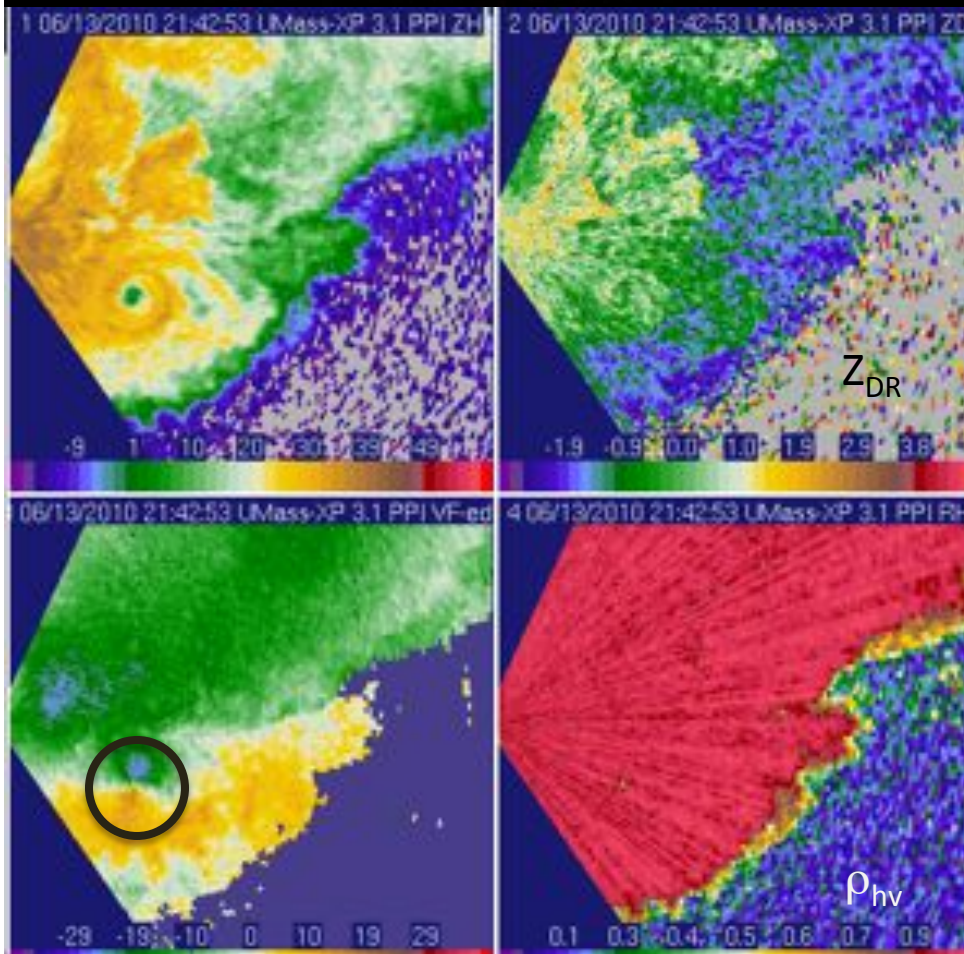


UMASS X-POL
LONG AFTER TORNADO SHOWN ABOVE





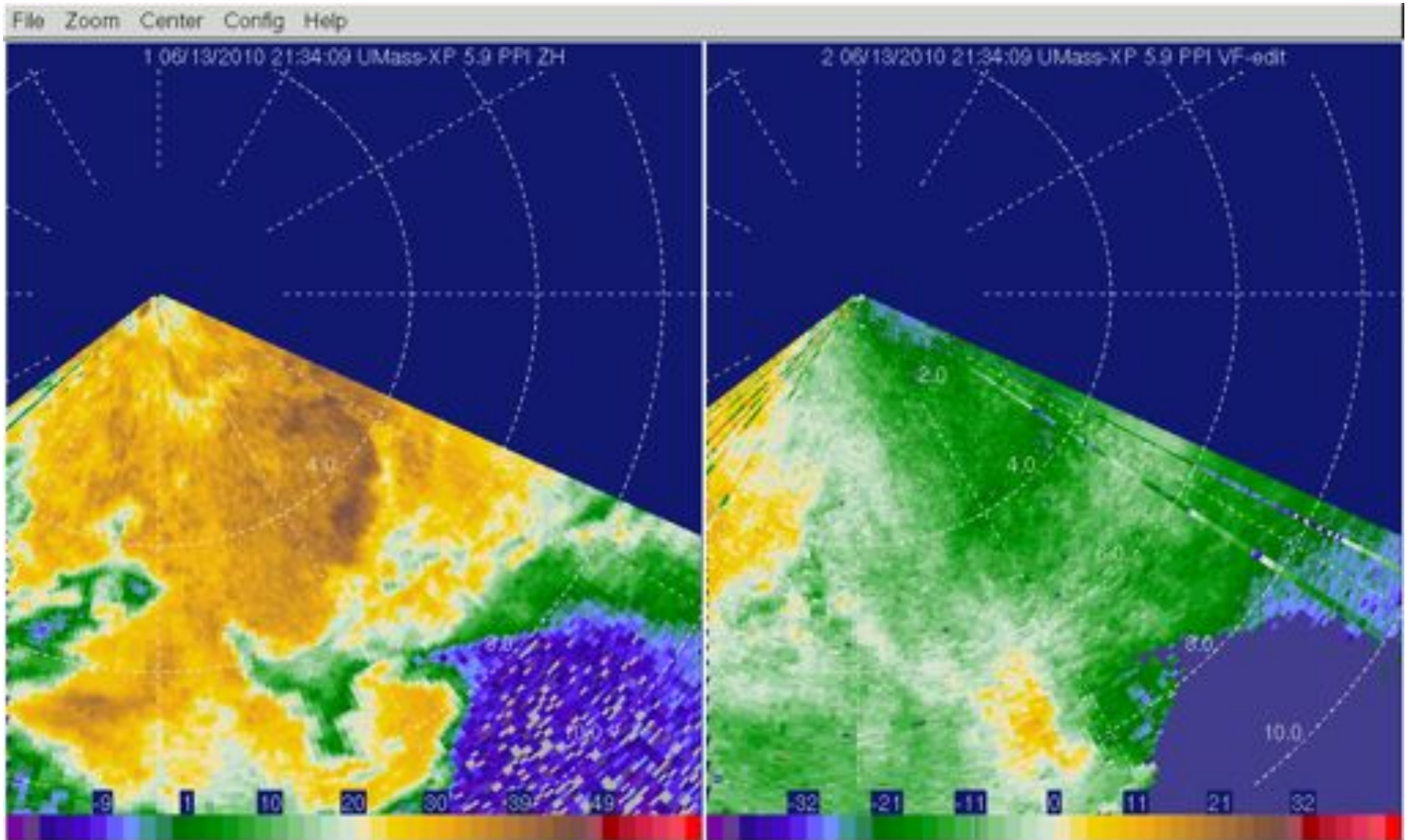
13 JUNE 2010
OK PANHANDLE
© H. Bluestein



RANGE ~ 2 km

Z

V

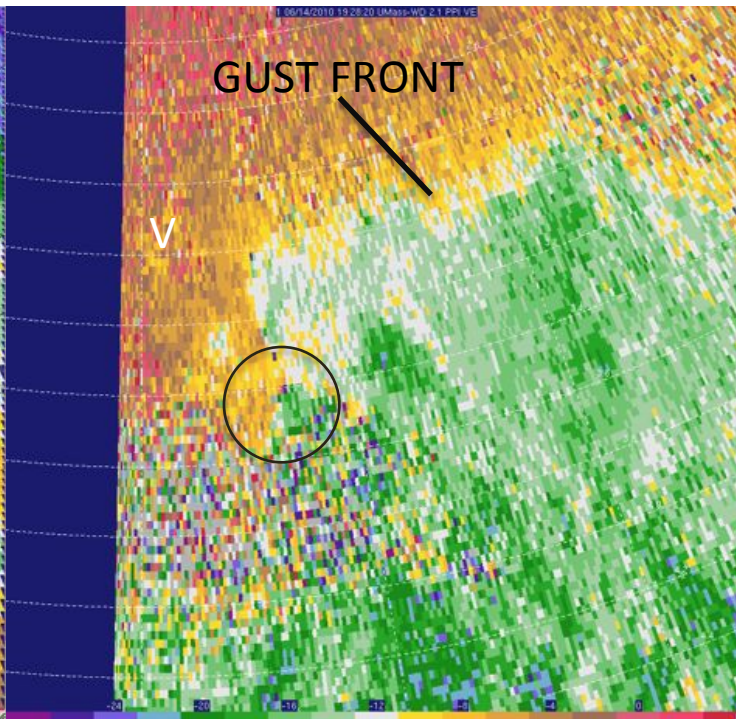
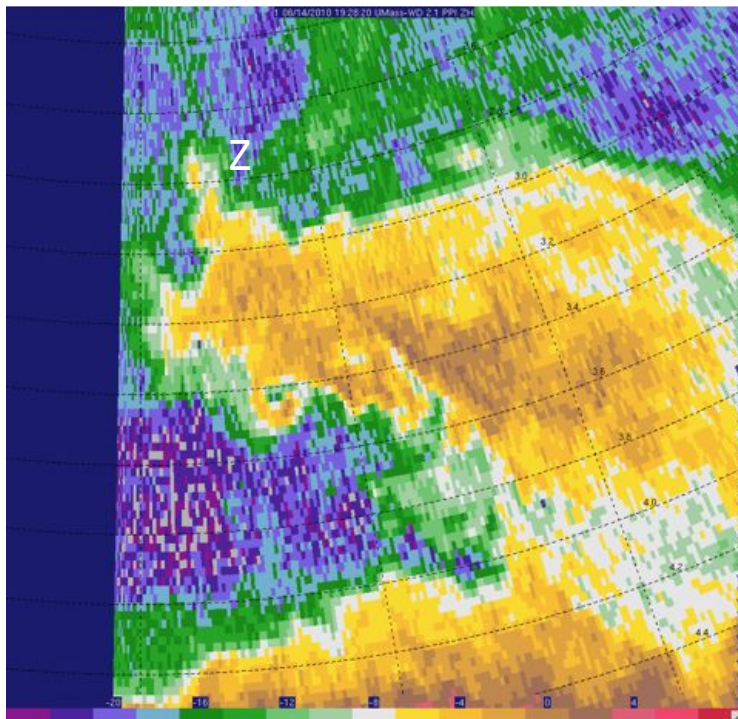


13 JUNE 2010 UMASS X-POL

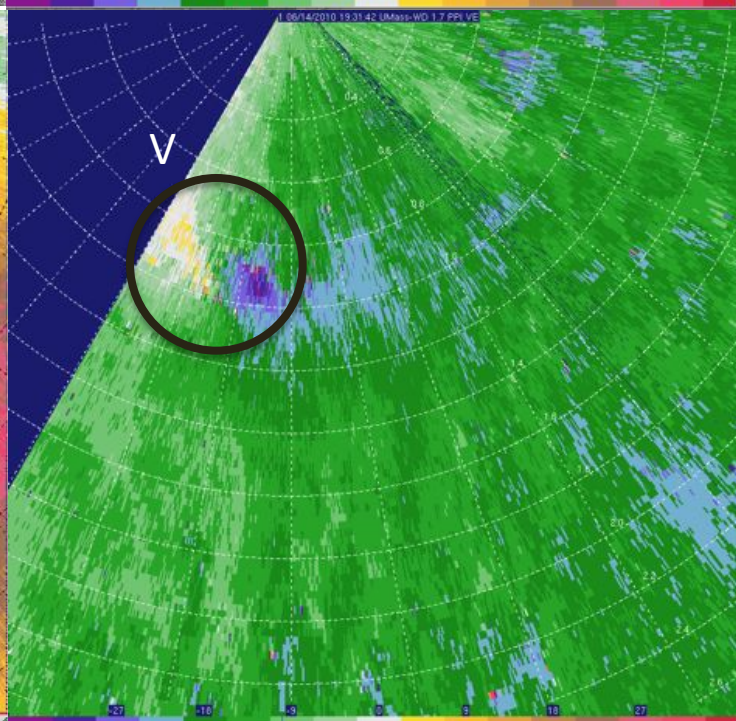
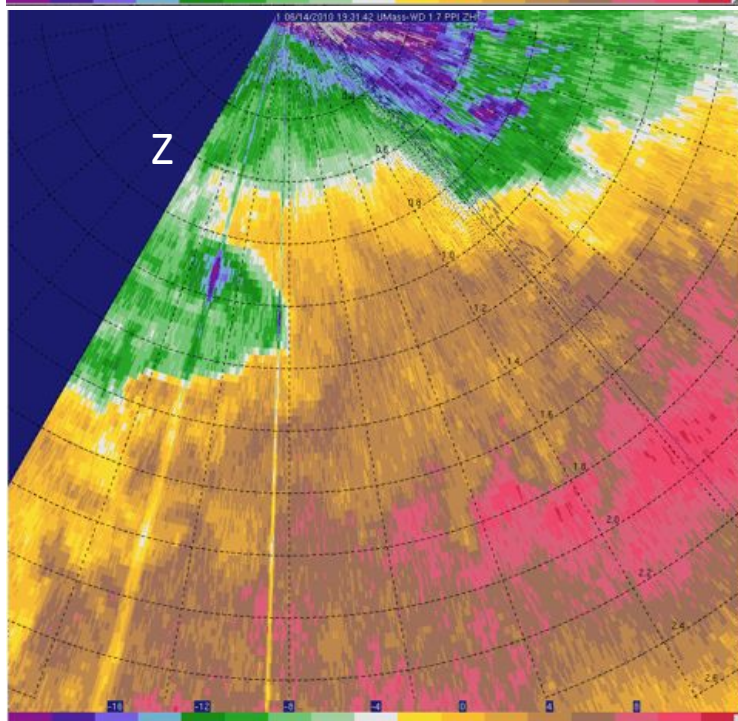


14 June 2010
SW TX
© H. Bluestein



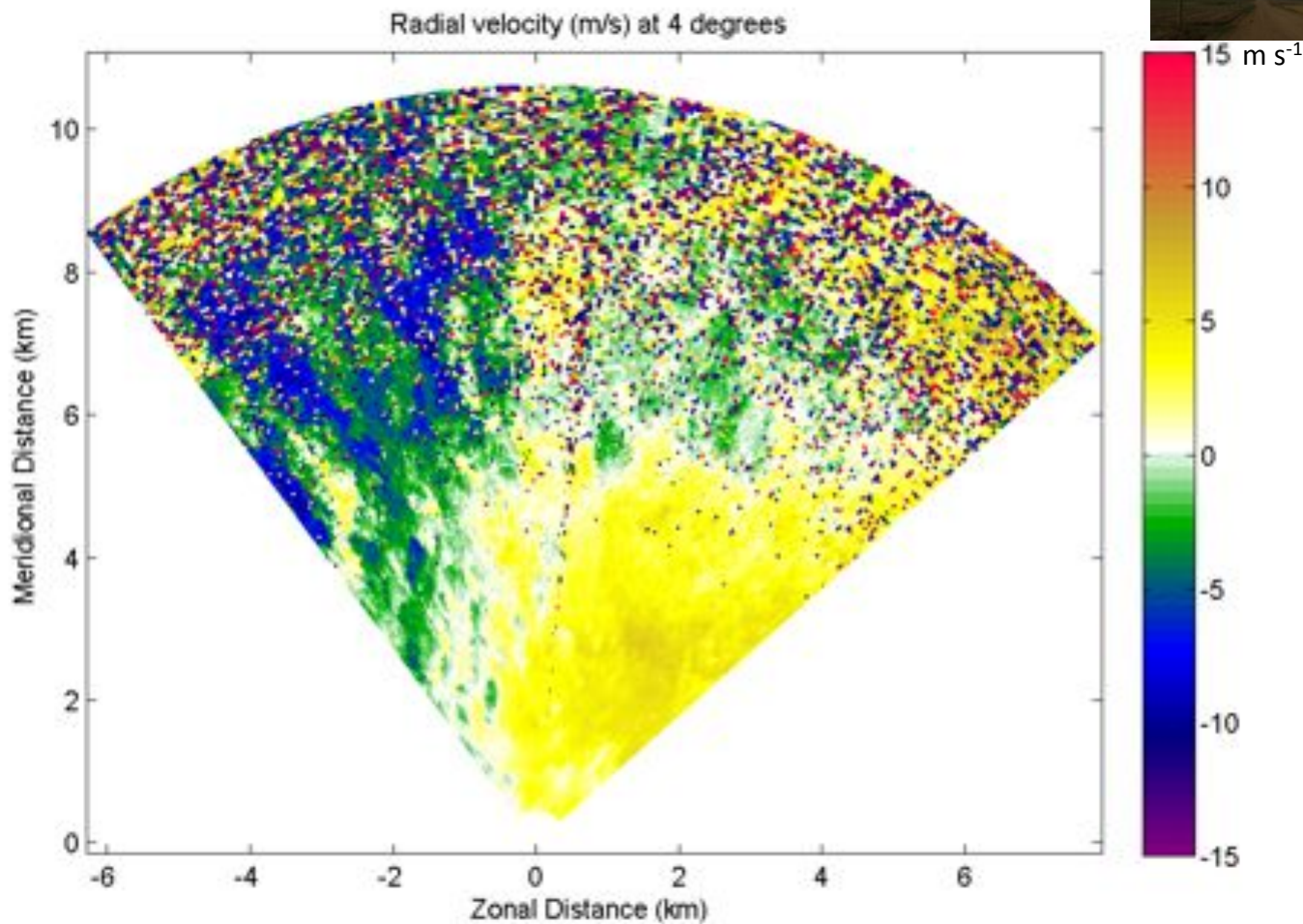


14 JUNE 2010
SW TX
UMASS W-BAND



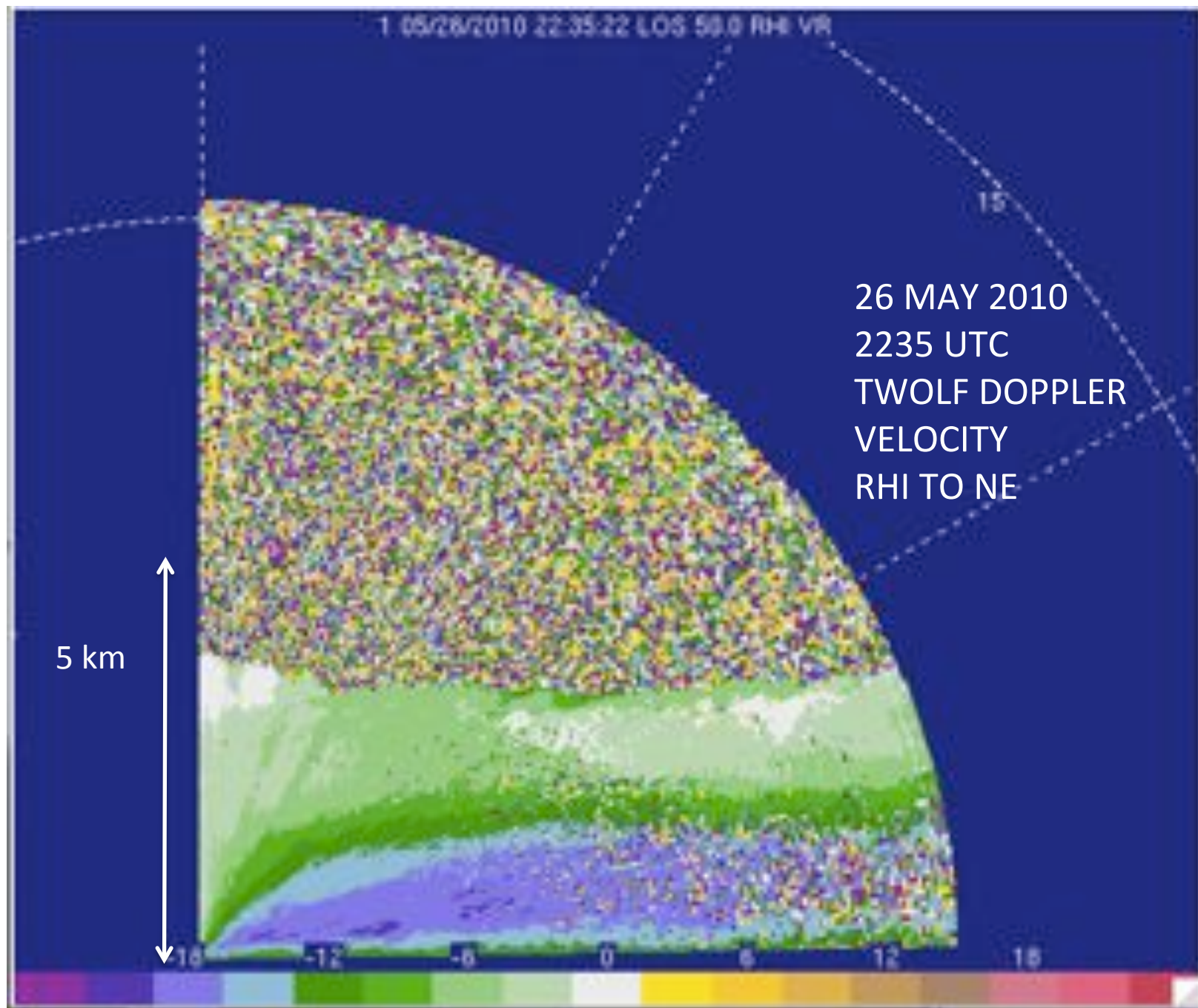
↓
W

5/26/10 2333 UTC 4° PPI
TWOLF E CO
(TRUCK-MOUNTED WIND-
OBSERVING LIDAR FACILITY)



© J. Houser

2321 UTC



RAPID X-POL (RaXPoI)

© H. Bluestein
22 May 2011



RaXPol SYSTEM PARAMETERS

Parameter	Value
Center Frequency	9.73 GHz +-20 MHz
Transmit Power	20 kW peak, 200 W ave.
Transmit Pulse Width	0.1 – 40 us
Transmit Waveform	RF Pulse, Linear or Custom Chirp
Transmit Polarization	Equal Power V&H
PRF	Uniform or Staggered
Antenna type	Dual-linear Polarized Parabolic Reflector
Antenna Diameter	2.4 m
Antenna Beamwidth	1.0° Half-power
Antenna Gain	44.5 dB
Pedestal Type	Elevation over Azimuth
Pedestal Scan Rate	180 deg s ⁻¹ Az, 36 deg s ⁻¹ El
Receiver type	Dual-channel (V & H-pol)
Receiver Noise Figure	3 dB
Receiver Bandwidth	0.5 to 40 MHz, or Custom
Range Gate Spacing	7.5 to 75 m
IF Frequency	90 MHz
Digital Receiver	Dual-channel, 16 bit ADC
Dynamic Range	90 dB @ 1 MHz Bandwidth
Processor	Industrial PC, Dual Quad-core 2.66 GHz Xeon
Clutter Filter	Coherent, User Defined Bandwidth

- ANTENNA SPINS AT 180° s⁻¹
- IT TAKES ~ 20 s TO SCAN VOLUME 1° – 20° WITH NO OVERLAPPING SCANS IN ELEVATION (10 STEPS EVERY 2°)
- RADAR TRANSMITS UNIFORMLY SPACED PULSE PAIRS, OR STAGGERED 3 PULSE GROUPS, WHILE SHIFTING THE FREQUENCY OF EACH GROUP BY THE PULSE BANDWIDTH NECESSARY TO ENSURE THE SAMPLES ARE INDEPENDENT
- DATA ACQUISITION CONFIGURED TO AVERAGE FOR 5 ms, TO ACQUIRE DATA FROM 12 PULSE PAIRS, EACH SPACED 200 μs
- DESIGNED BY ANDY PAZMANY, PROSENSING, INC.
- FUNDING FROM NSF MRI GRANT

23 May 2011
© H. Bluestein
SW OK

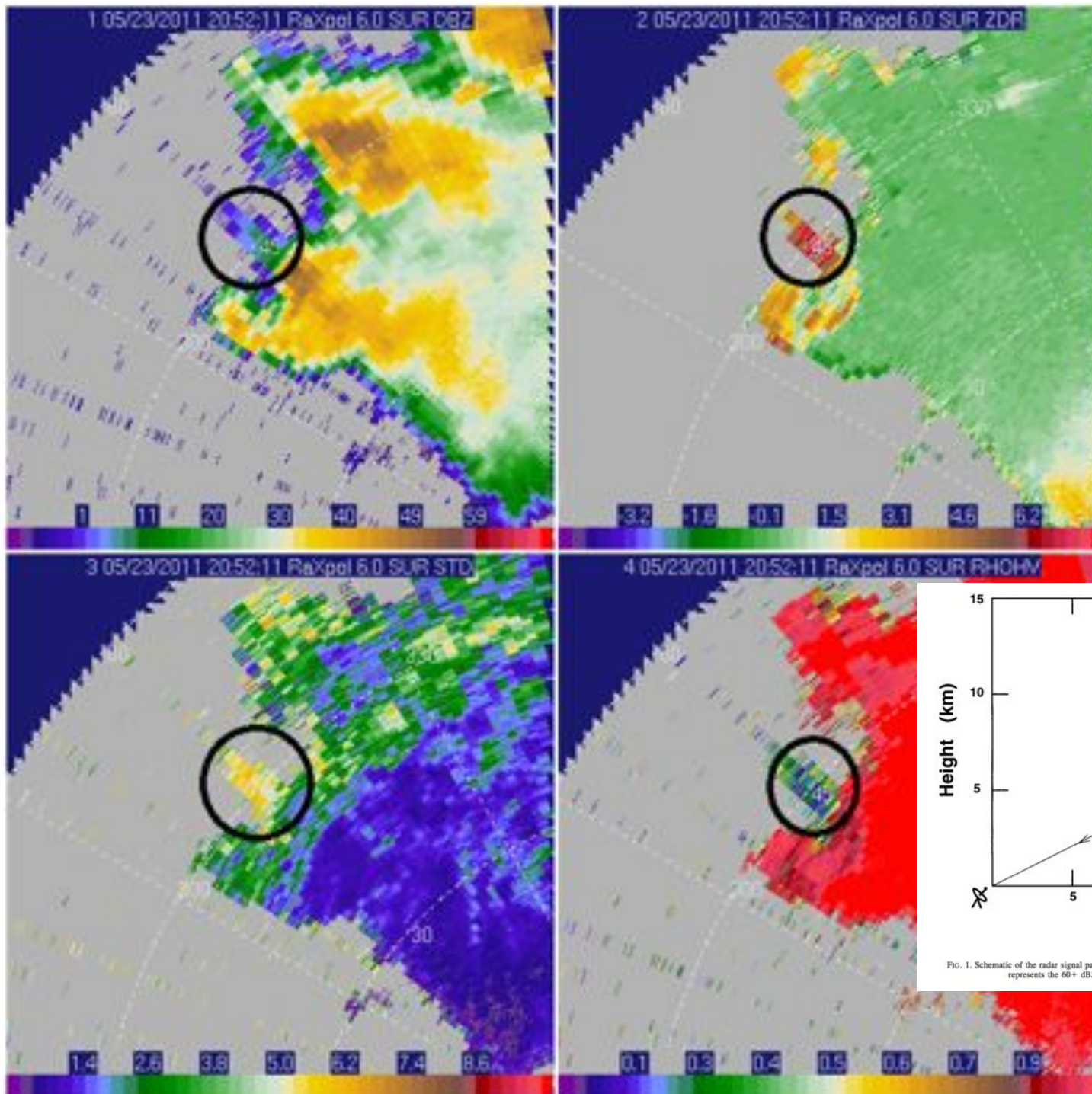




23 May 2011
© H. Bluestein
SW OK



LARGEST HAILSTONE EVER DOCUMENTED IN OKLAHOMA
23 MAY 2011 GOTEBO, OK (SW OK)
PHOTO COURTESY OF SCOTT BLAIR AND DEREK DEROCHE



• POLARIMETRIC
SIGNATURES OF
THREE-BODY
SCATTERING DUE
TO LARGE HAIL

(COURTESY OF
JEFF SNYDER)

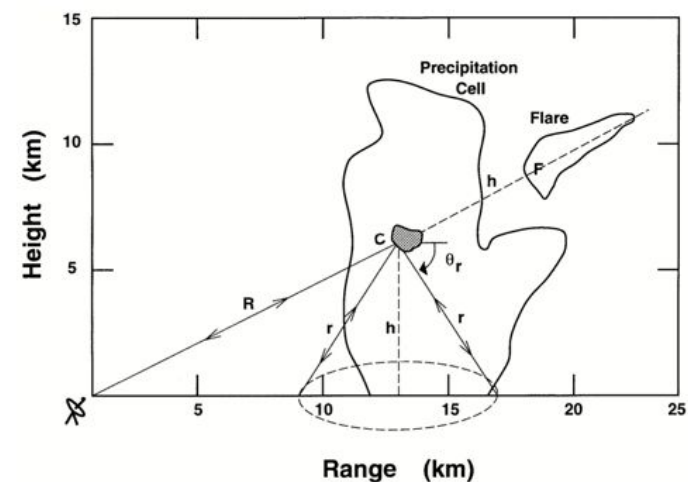
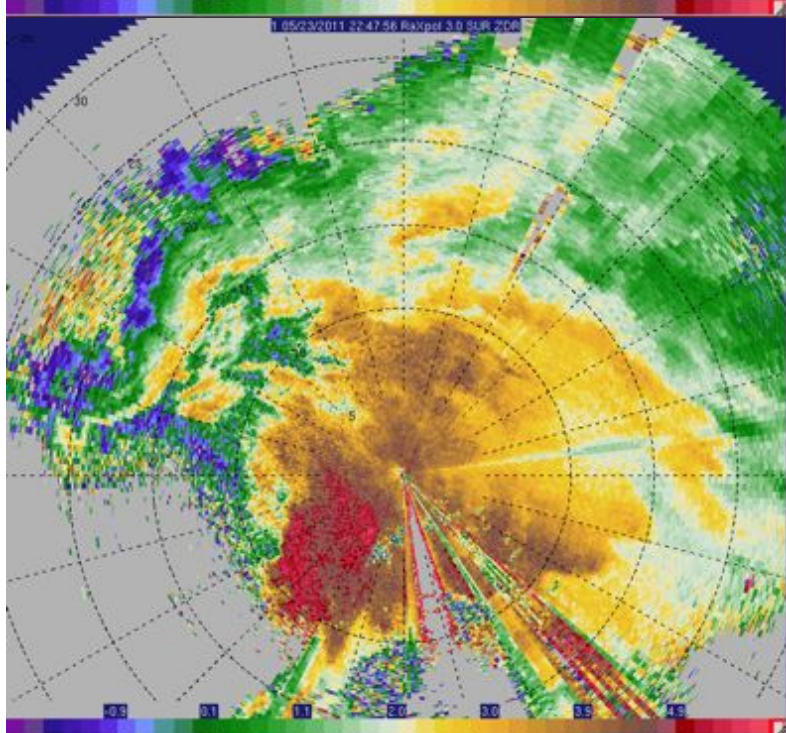
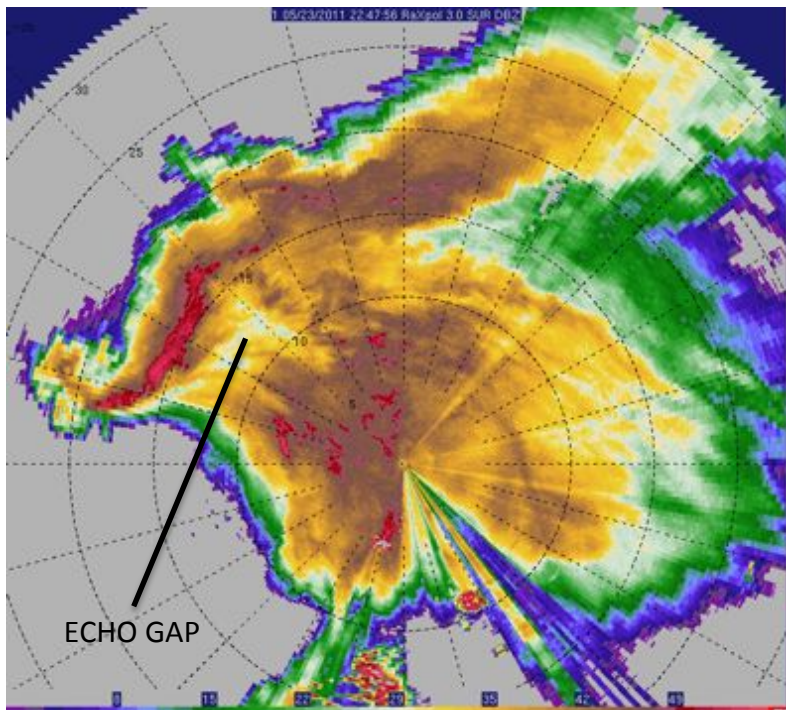
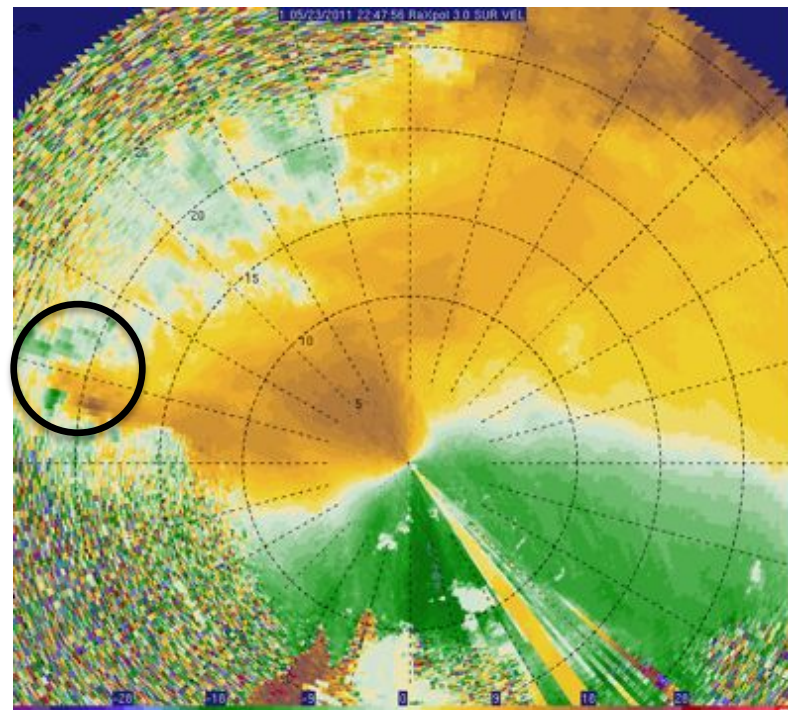


FIG. 1. Schematic of the radar signal path responsible for the three-body scatter spike (or flare echo). The dark shading near point C represents the 60+ dBZ core responsible for producing the artifact, from Wilson and Reum (1988).



Z

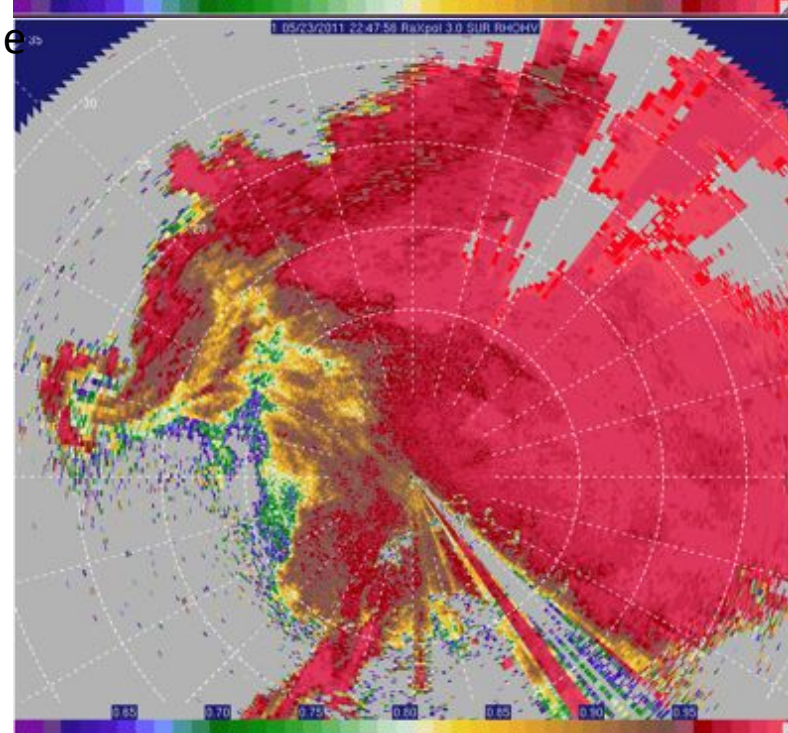
V

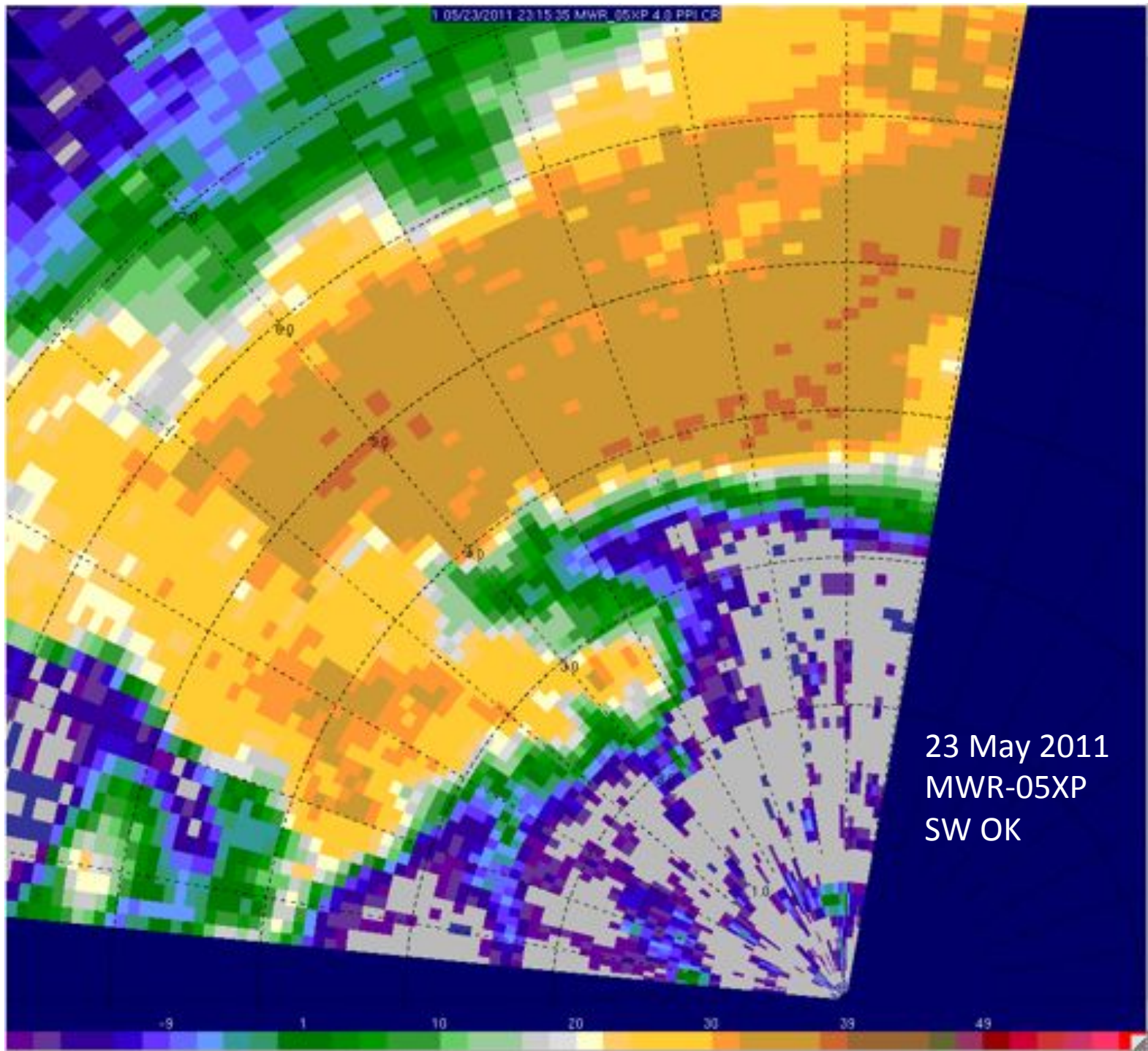


RaXPol
3° elevation angle
23 May 2011
2247:56 UTC
SW OK

Z_{dr}

ρ_{hv}







23 May 2011: THE DOG DAYS OF
STORM SEASON

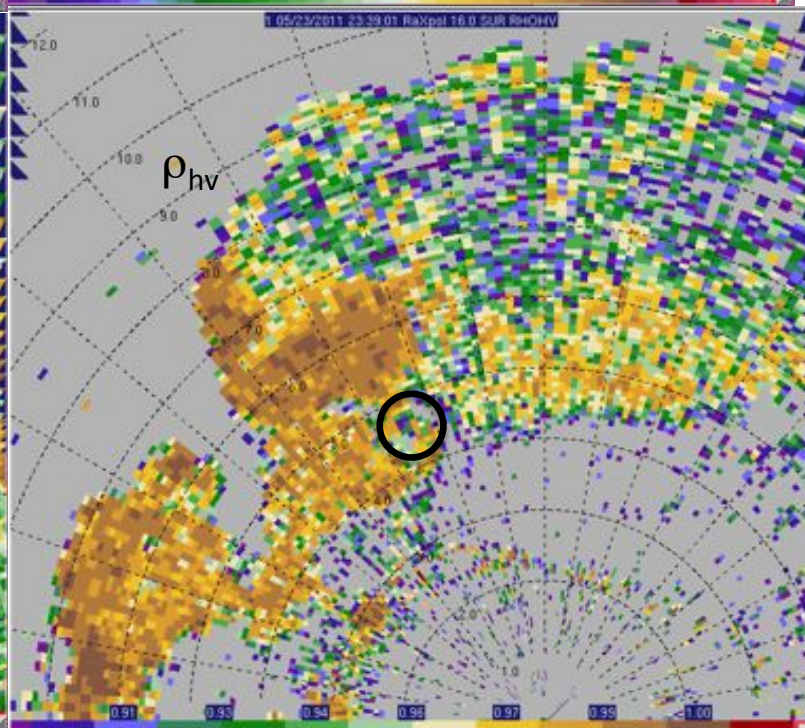
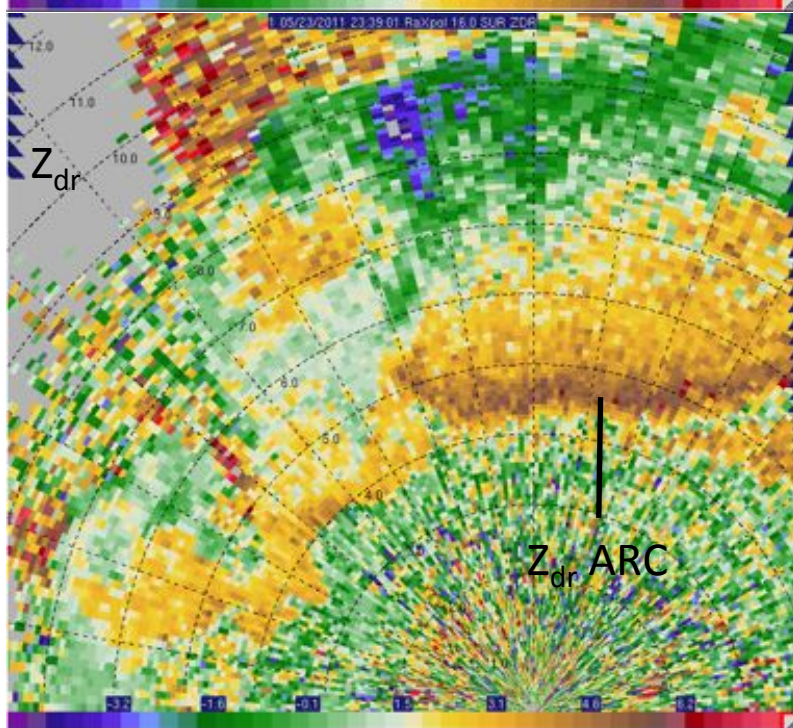
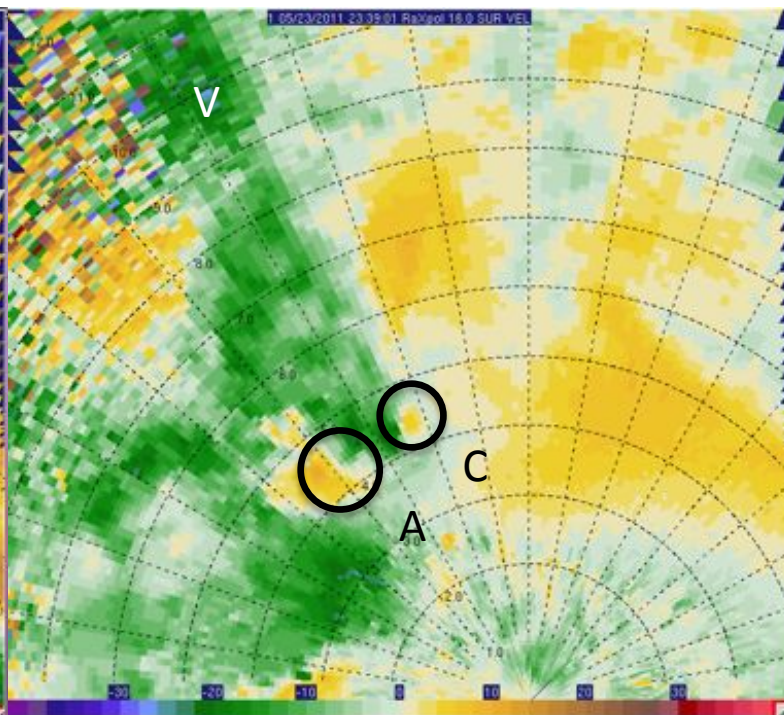
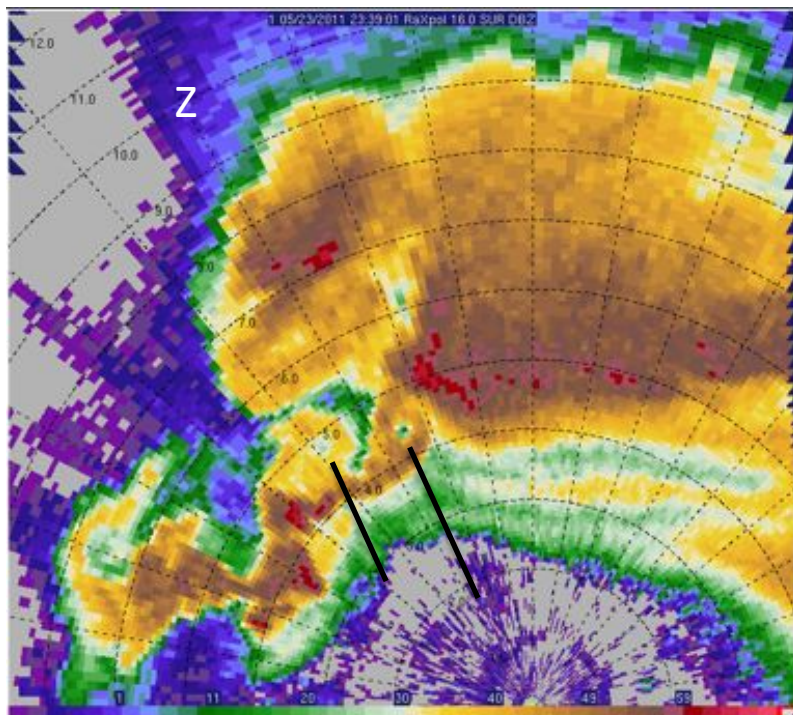
DOG INSPECTING MWR-05XP,
A “K9-BAND” RADAR?

DOG BEING ENTICED TO LEAVE
MWR-05XP

© Jana Houser

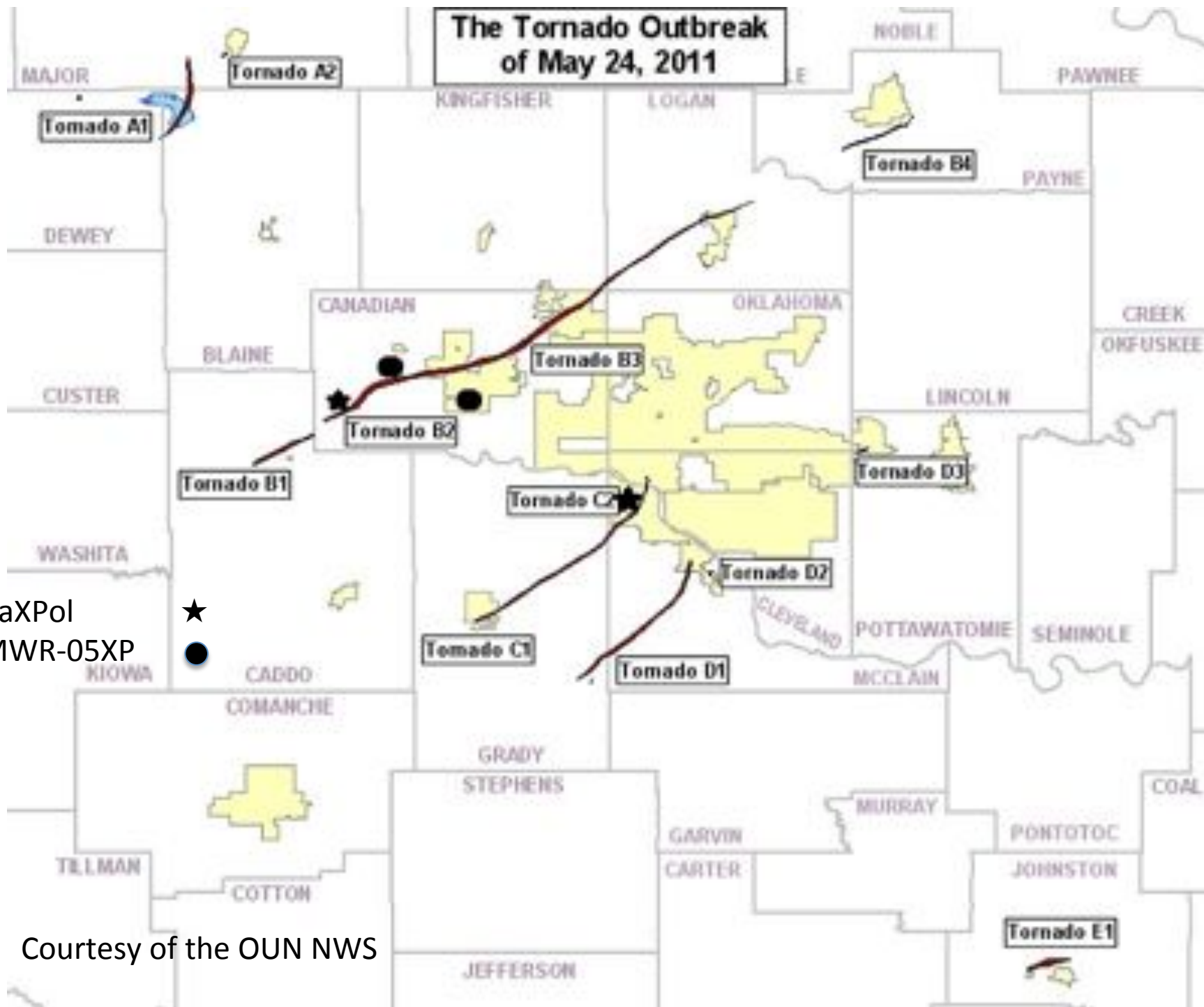
23 May 2011
© H. Bluestein
SW OK





RaXPol
 16⁰ elev. angle
 23 May 2011
 2339:01 UTC
 SW OK

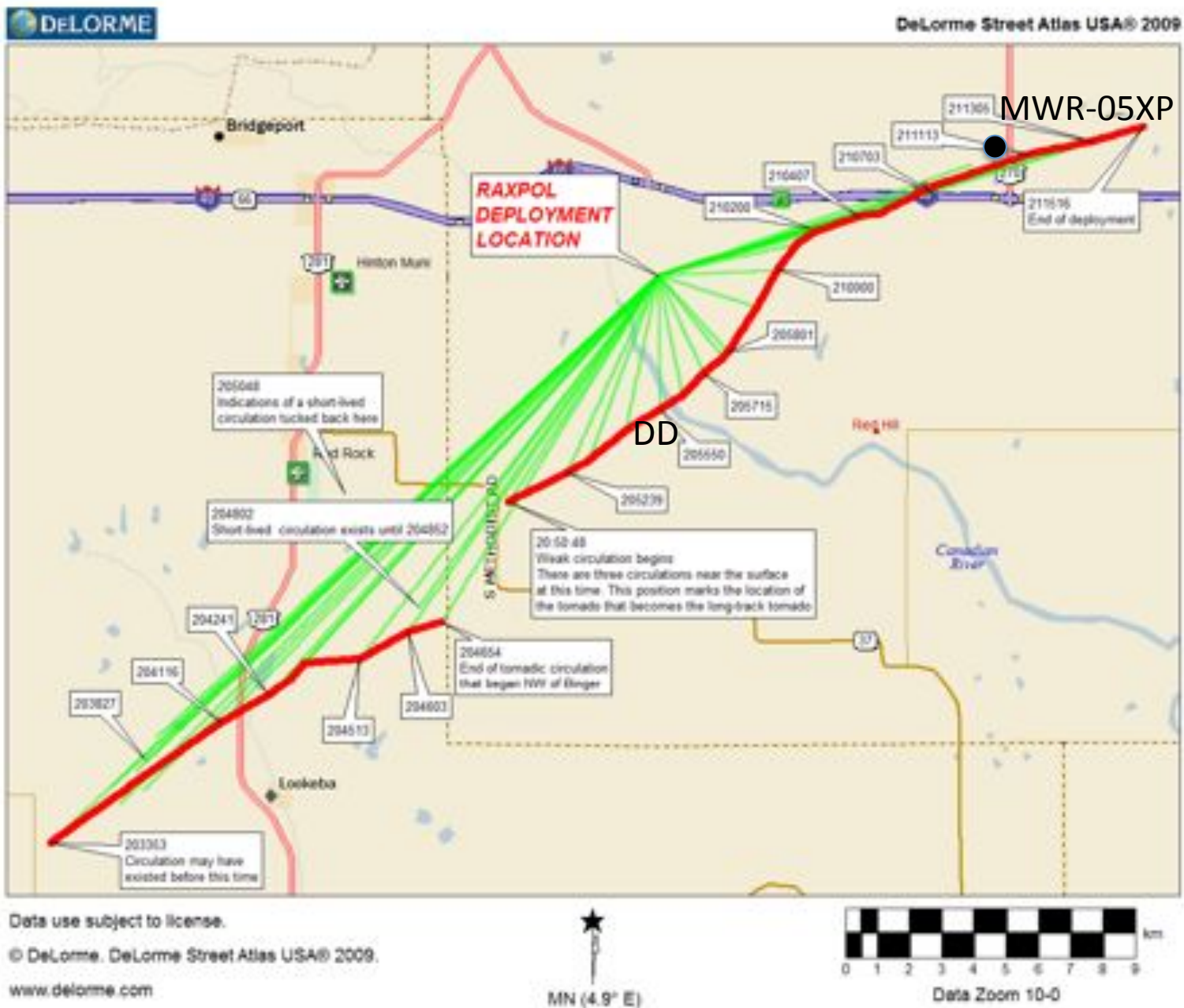
The Tornado Outbreak of May 24, 2011



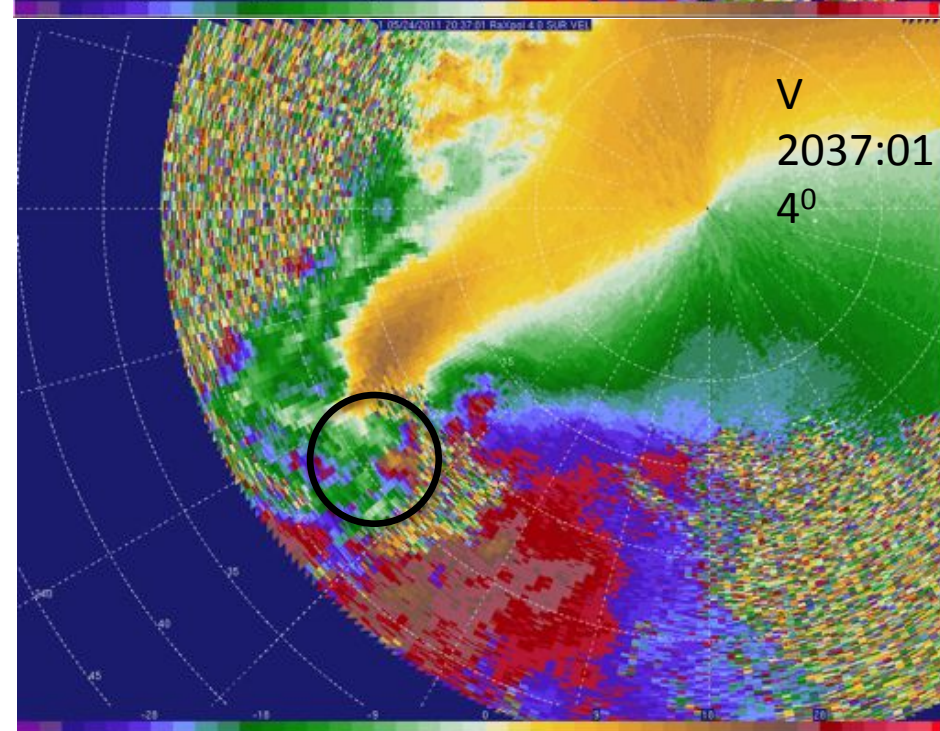
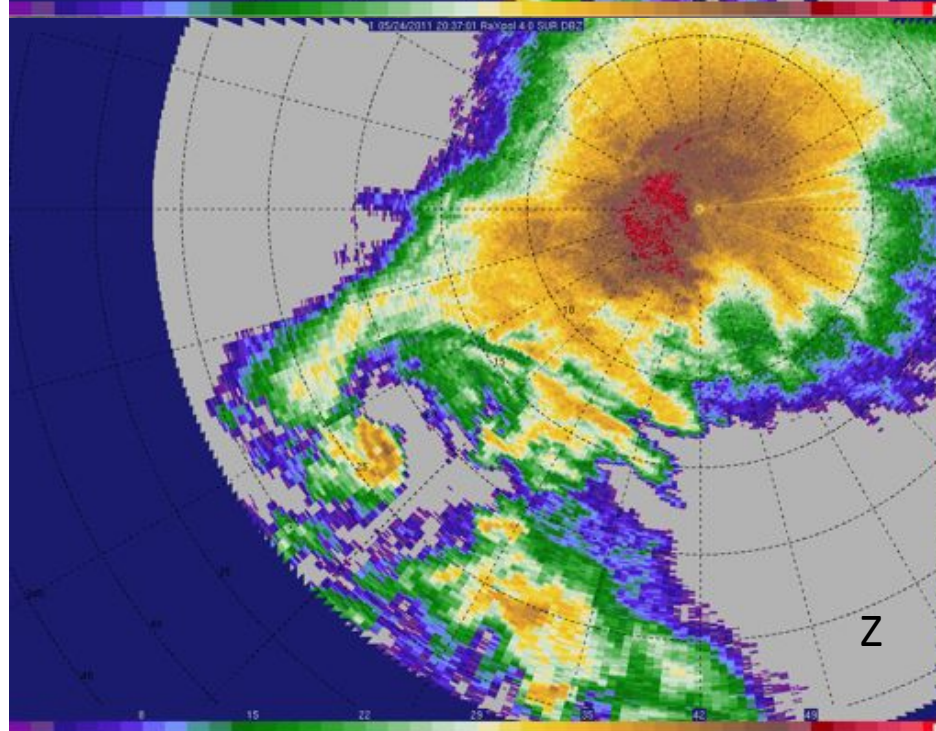
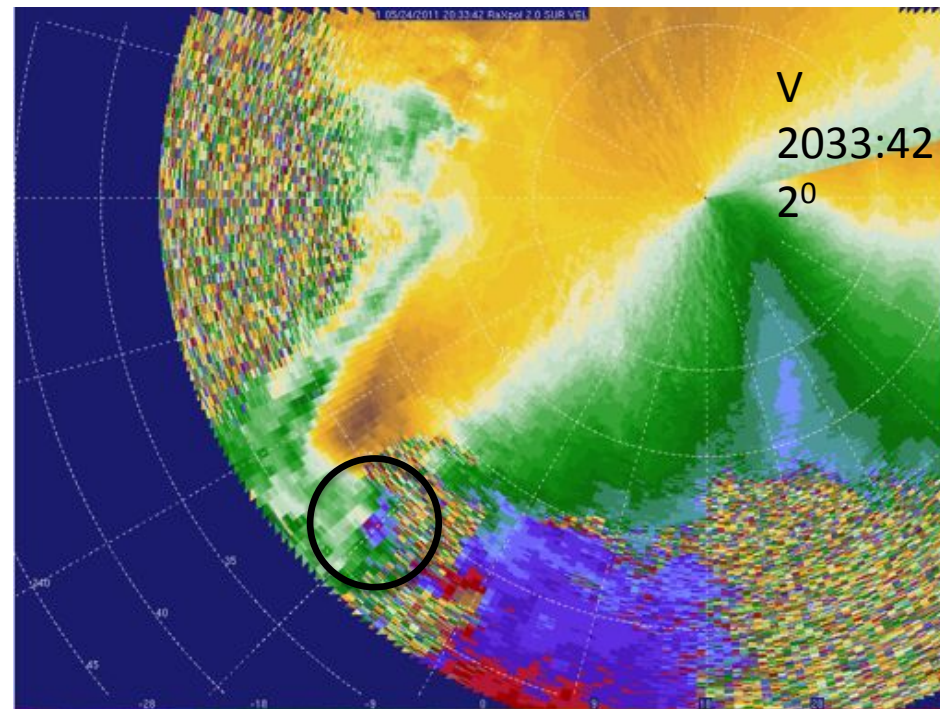
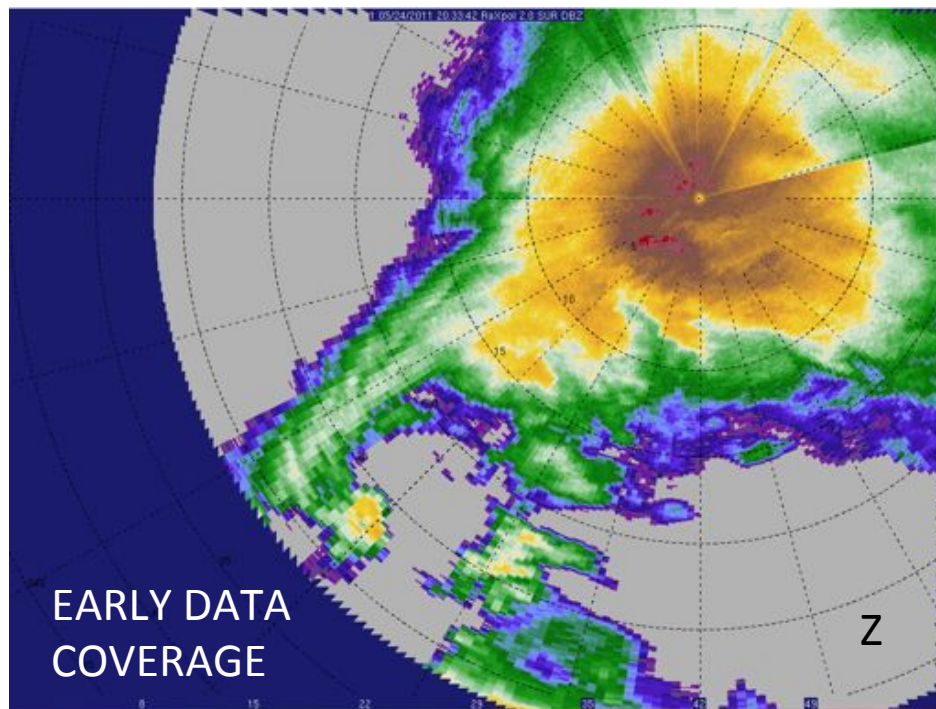
RaXPol
MWR-05XP

Courtesy of the OUN NWS

Deployment	Radar	Start Time	End Time	Elevations	Scan Strategy
1	RaxPol	202132	203515	2,4,6,8,10,12,14,16,18	PPI ~115 sec volumes
	RaxPol	203643	205456	(2),4,6,8,10,12,14,16,18	PPI ~16 sec volumes
~ 57 min	RaxPol	205524	210141	1	PPI ~2 sec updates
	RaxPol	210207	211818	(2),3,5,7,9,11,13,15,17	PPI ~16 sec volumes
1	MWR	204928	205615	Every 1.5 degs from 1-40	PPI ~11 sec volumes
2	MWR	213338	220300	Every 1.5 degs from 1-40	PPI ~11 sec volumes
2	RaxPol	224733	225053	(2),4,6,8	PPI ~47 sec volumes
	RaxPol	225154	230654	(2),4,6,8	PPI ~7 sec volumes

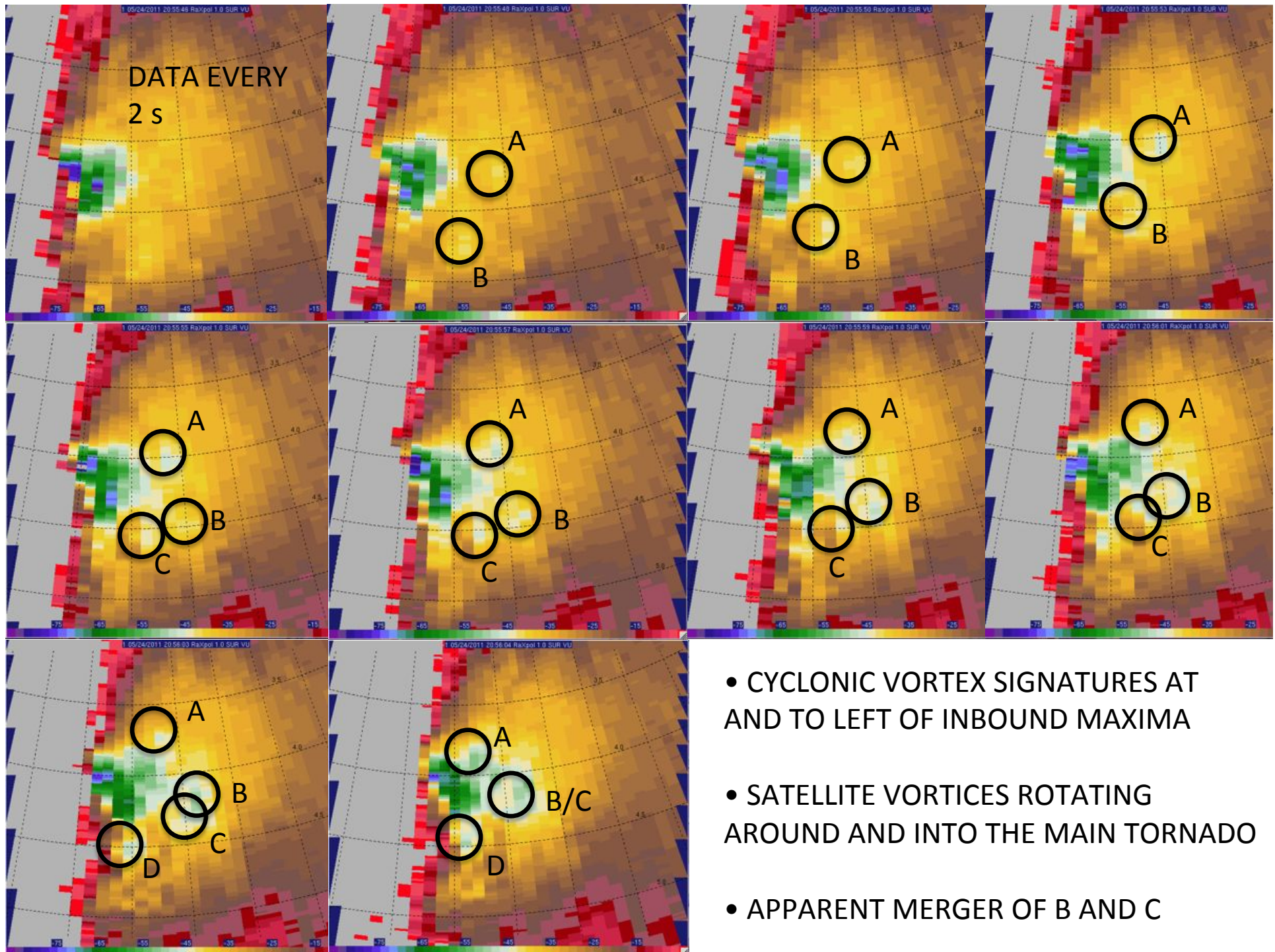


COURTESY OF JEFF SNYDER

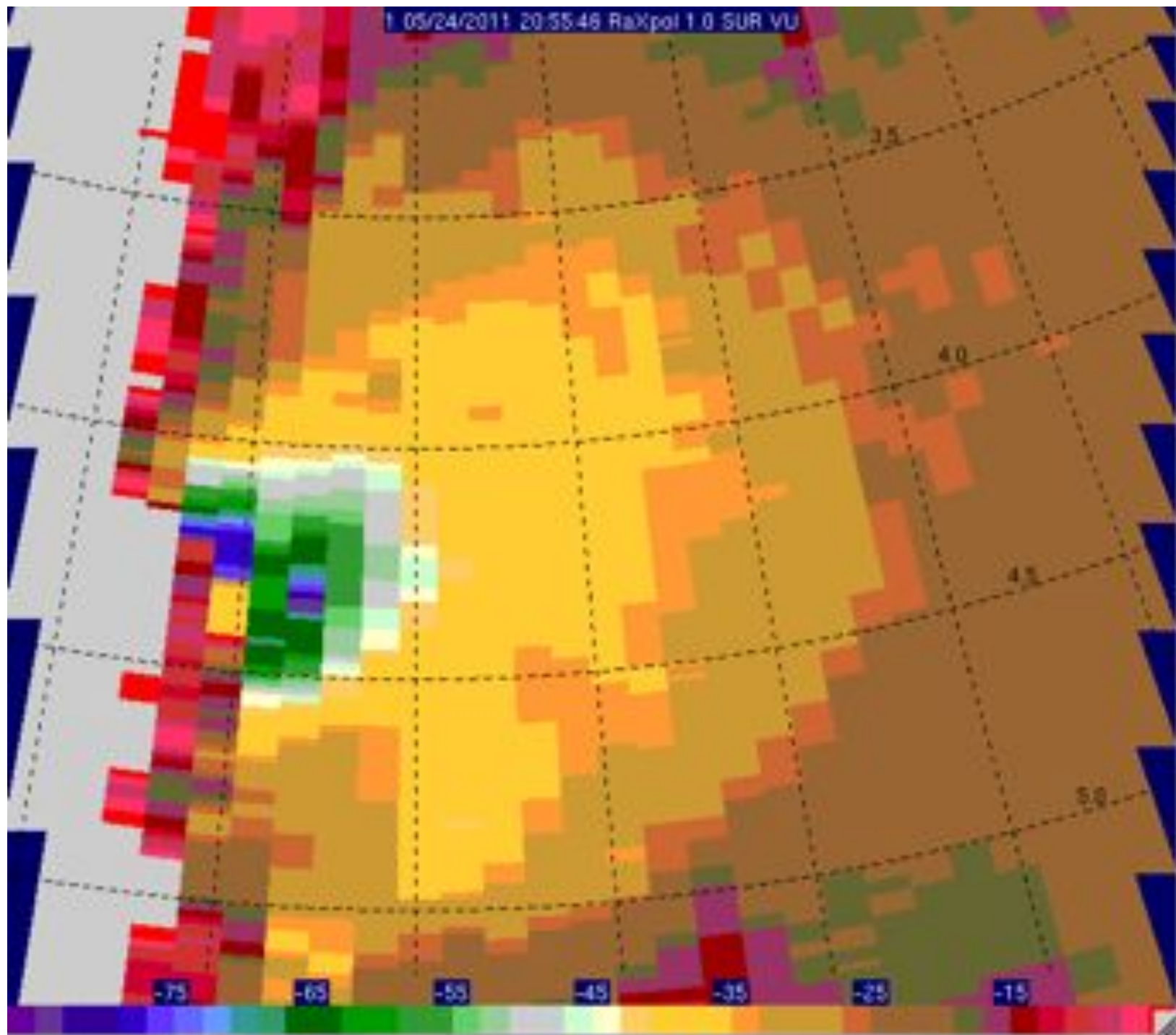




24 May 2011
© H. Bluestein



- CYCLONIC VORTEX SIGNATURES AT AND TO LEFT OF INBOUND MAXIMA
- SATELLITE VORTICES ROTATING AROUND AND INTO THE MAIN TORNADO
- APPARENT MERGER OF B AND C



SATELLITE
VORTICES



24 May 2011
© H. Bluestein



24 May 2011
© H. Bluestein

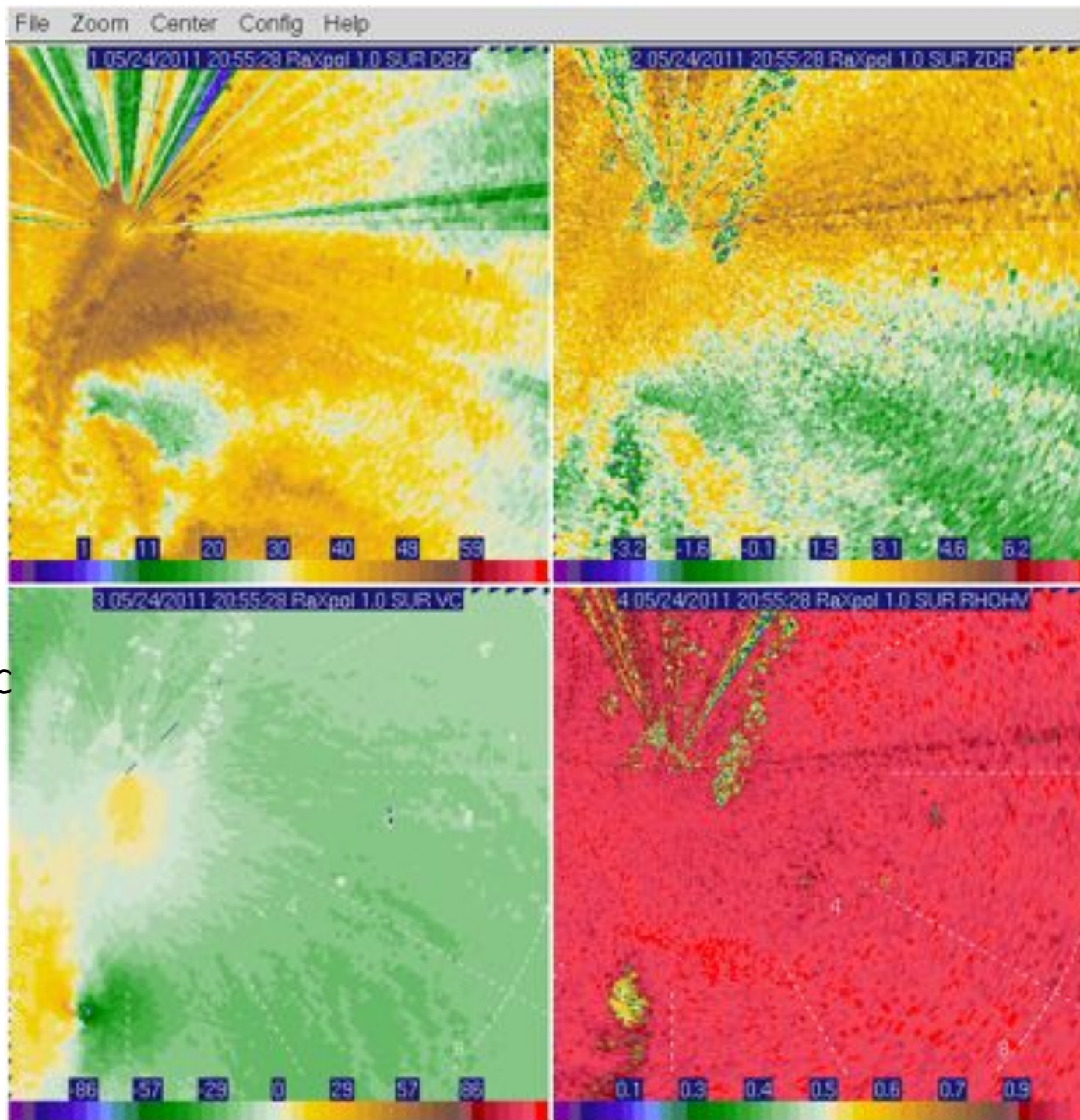
© H. Bluestein

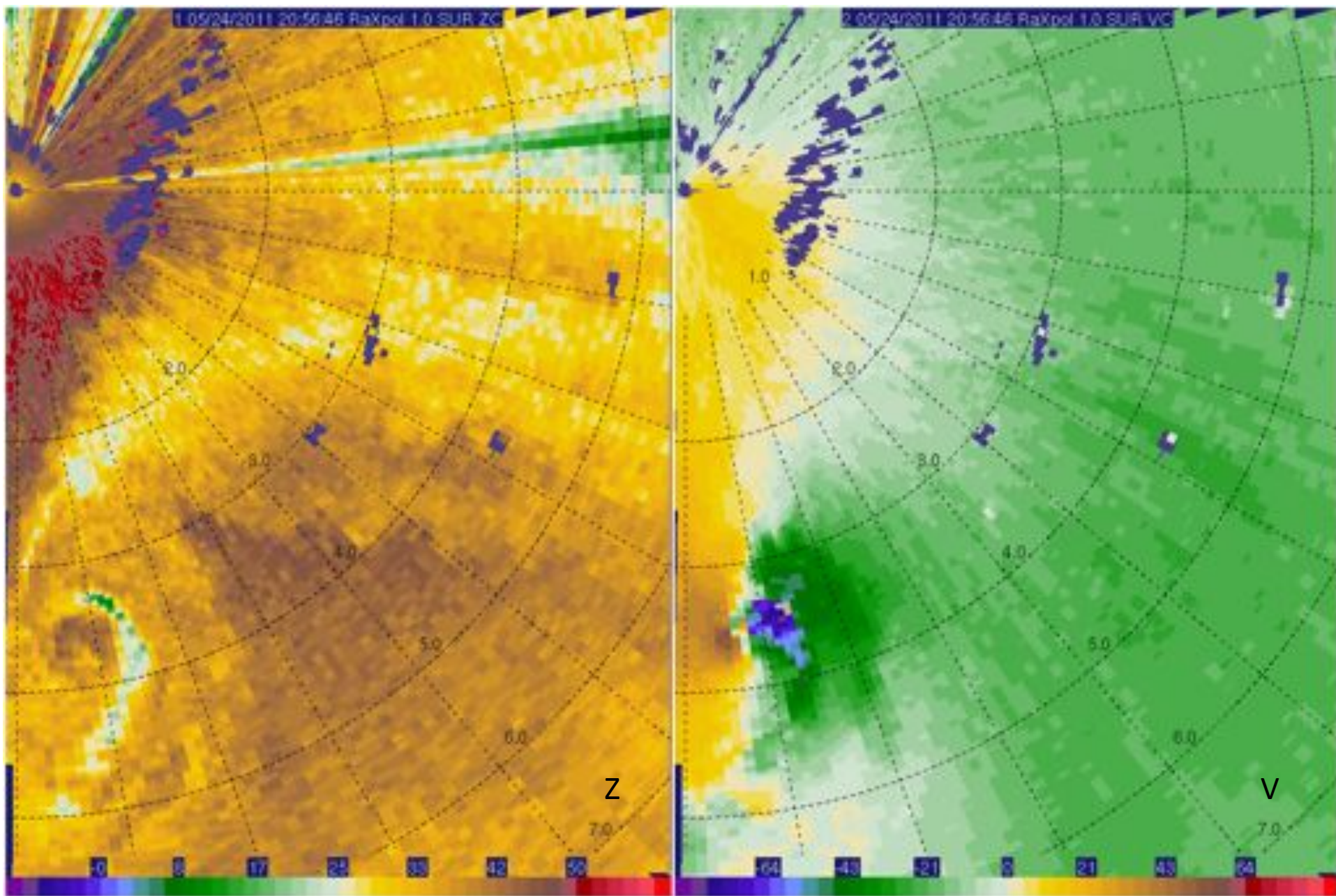


© H. Bluestein



RaXPol
UPDATES
2056:46 –
2059:41 UTC





RaXPol UPDATES EVERY 2 s 2056:46 – 2059:41 UTC

- RADAR REFLECTIVITY SHOWS GOOD TEMPORAL CONTINUITY AT RAPID-SCAN RATES
- ANALYSIS OF 3D WINDS FROM JUST ONE DOPPLER RADAR, MAKING USE OF HIGH TEMPORAL RESOLUTION

RADAR IS AT (0,0)

$$V_r = [1/(x^2 + y^2 + z^2)^{1/2}] [x u + y v + z (w + W_t)]$$

$$W_t \sim Z, Z_{dr}, \rho_{hv}$$

$$\partial R / \partial t = -u \partial R / \partial x - v \partial R / \partial y - w \partial R / \partial z$$

$$R \sim Z \quad \text{IGNORE SOURCE AND SINK TERMS}$$

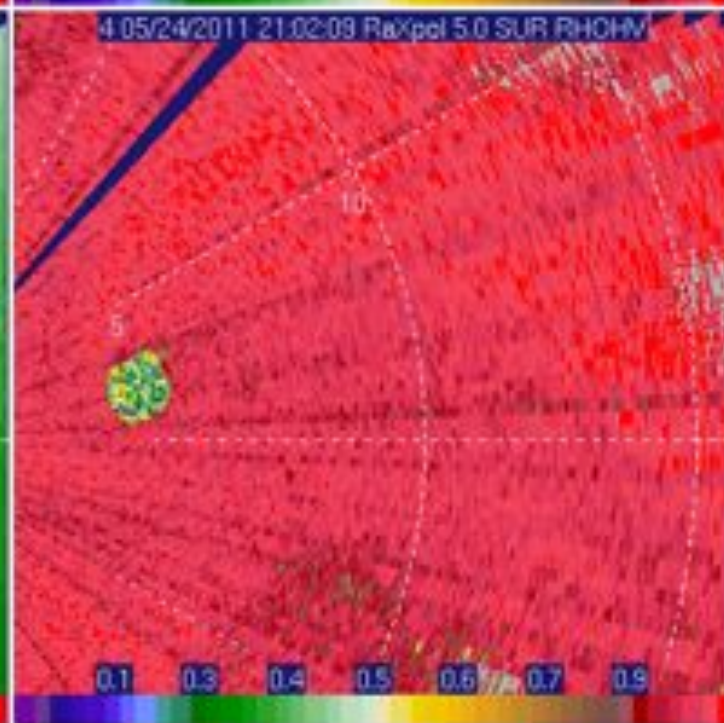
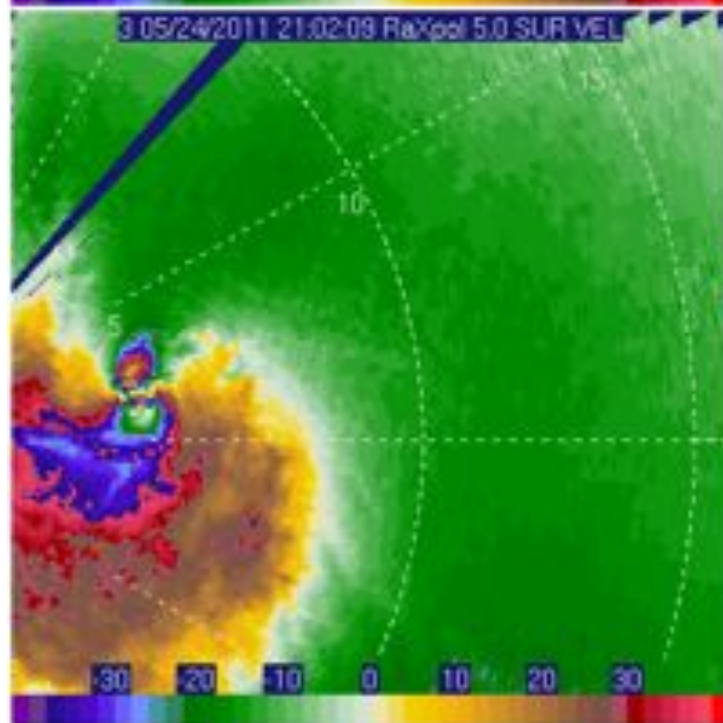
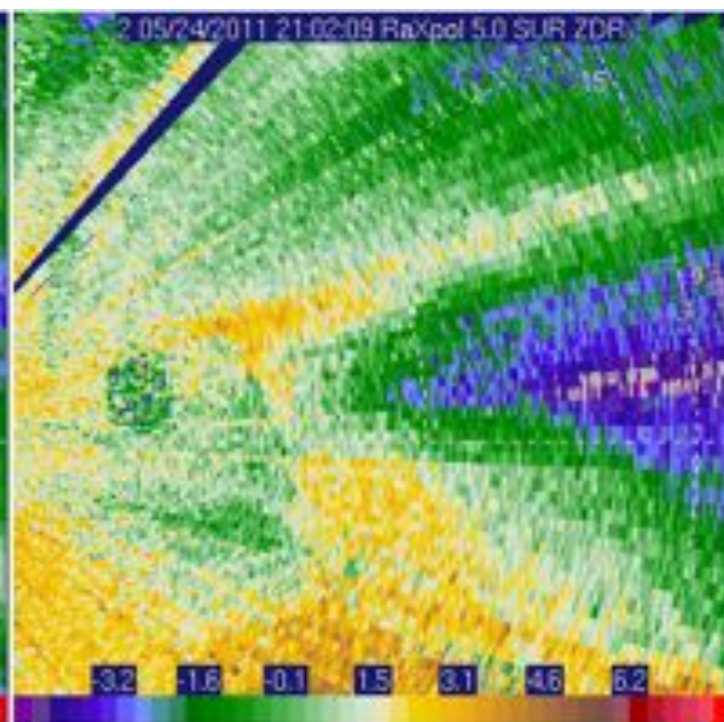
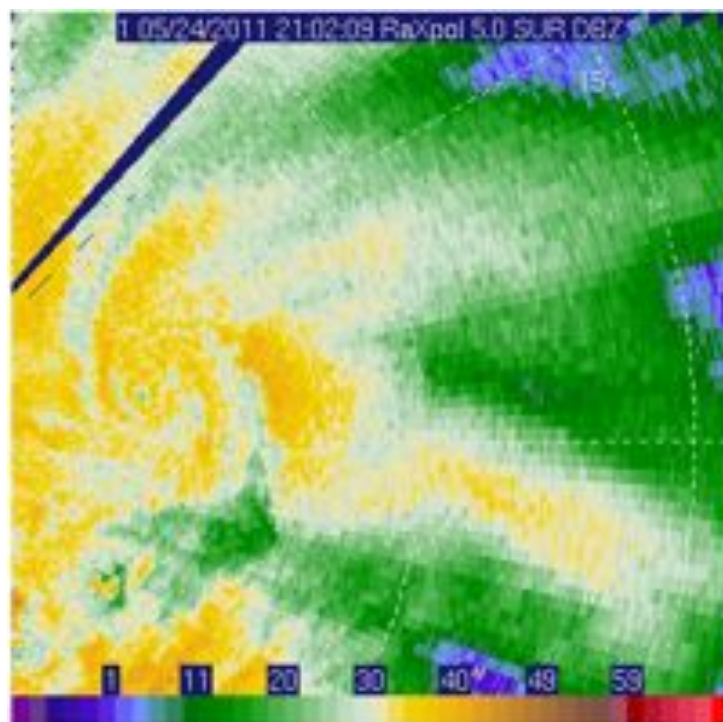
$$\partial u / \partial x + \partial v / \partial y + \partial w / \partial z = 0$$

B. C.'s: $w = 0$ at $z = 0$ and $z = \text{top}$

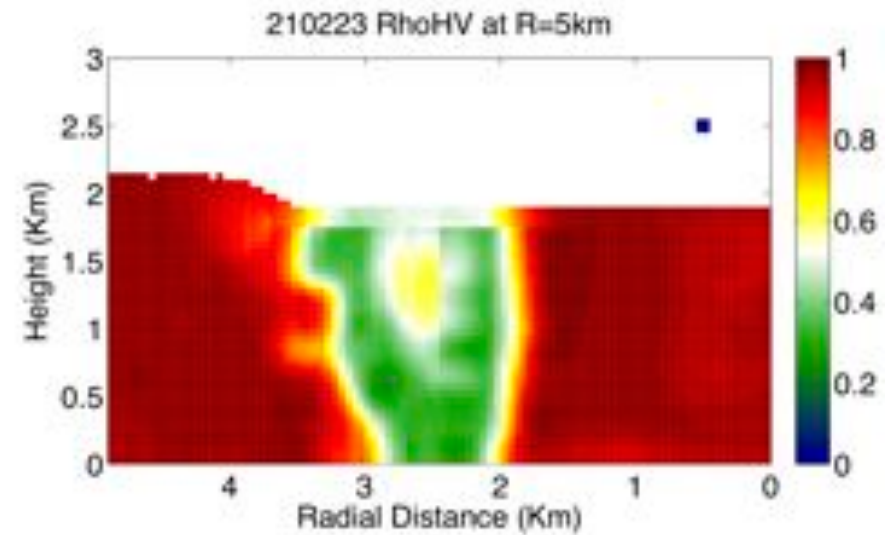
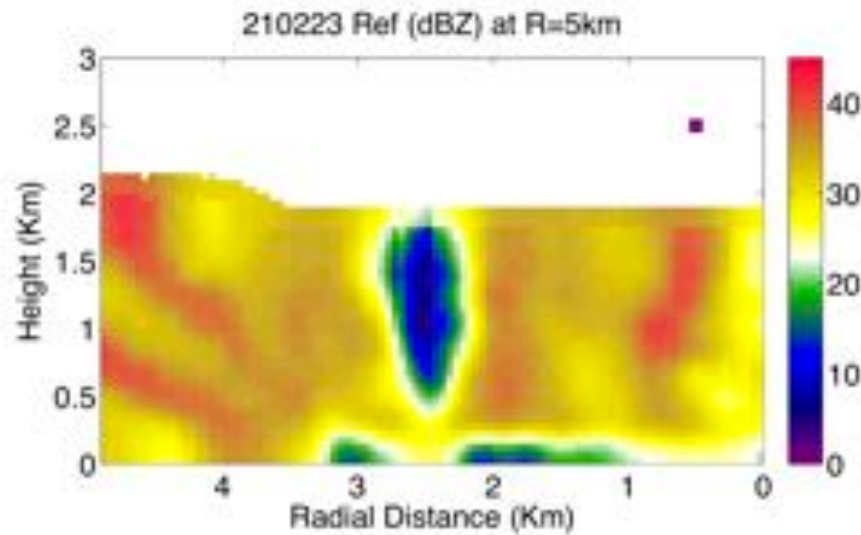
3 EQUATIONS IN 3 UNKNOWNNS (u, v, w)

SOLVE: MAY LATER USE TIME-DEPENDENT VORTICITY EQUATION AS A WEAK CONSTRAINT

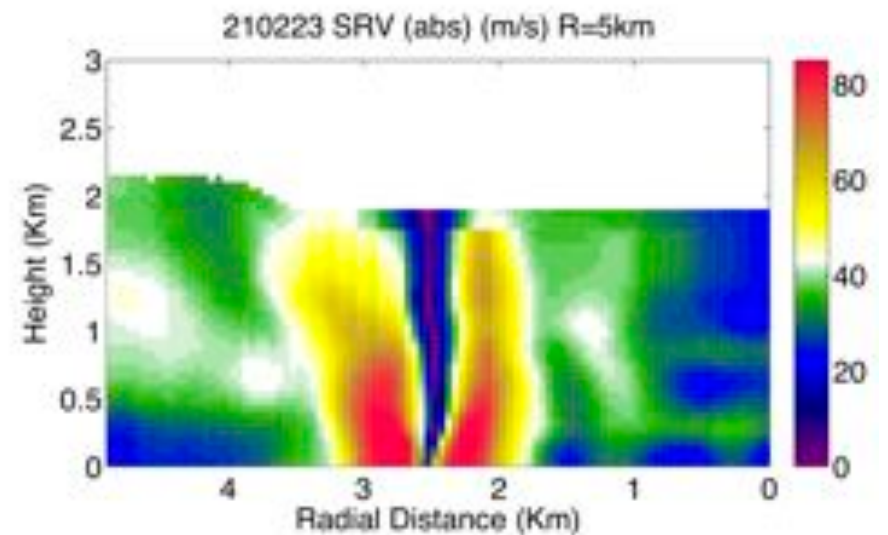
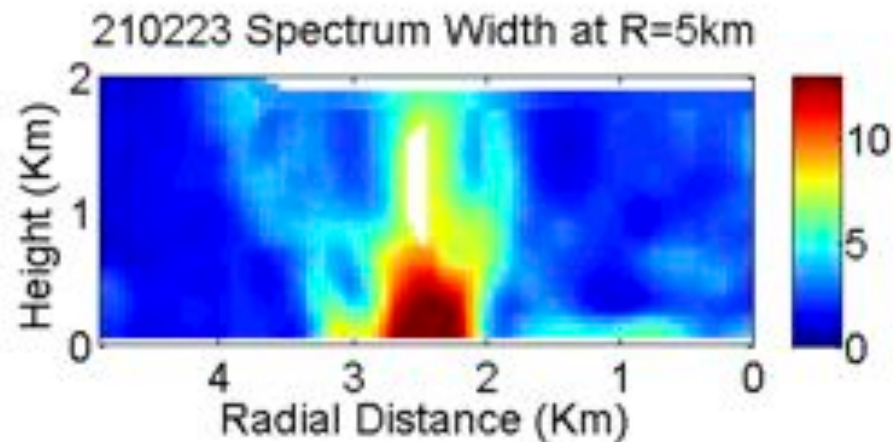
- FIRST TEST: USE TREC TO ESTIMATE u and v ; THEN ADJUST u and v TO FIT V_r



- SHOW SYNCHRONIZED VIDEO AND RADAR DATA AT REAL-TIME SPEED



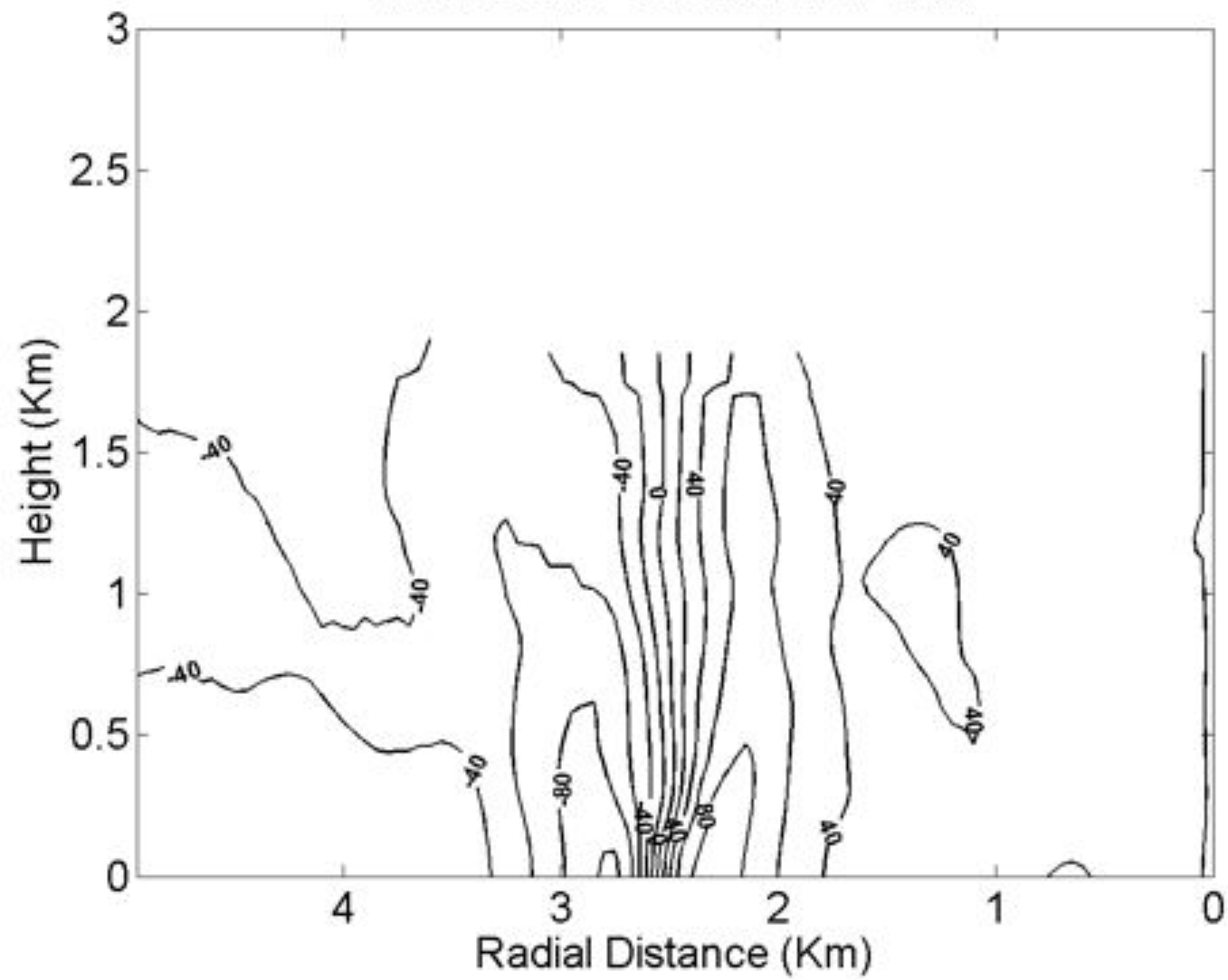
(THRESHOLDED AT 10 dBZ)



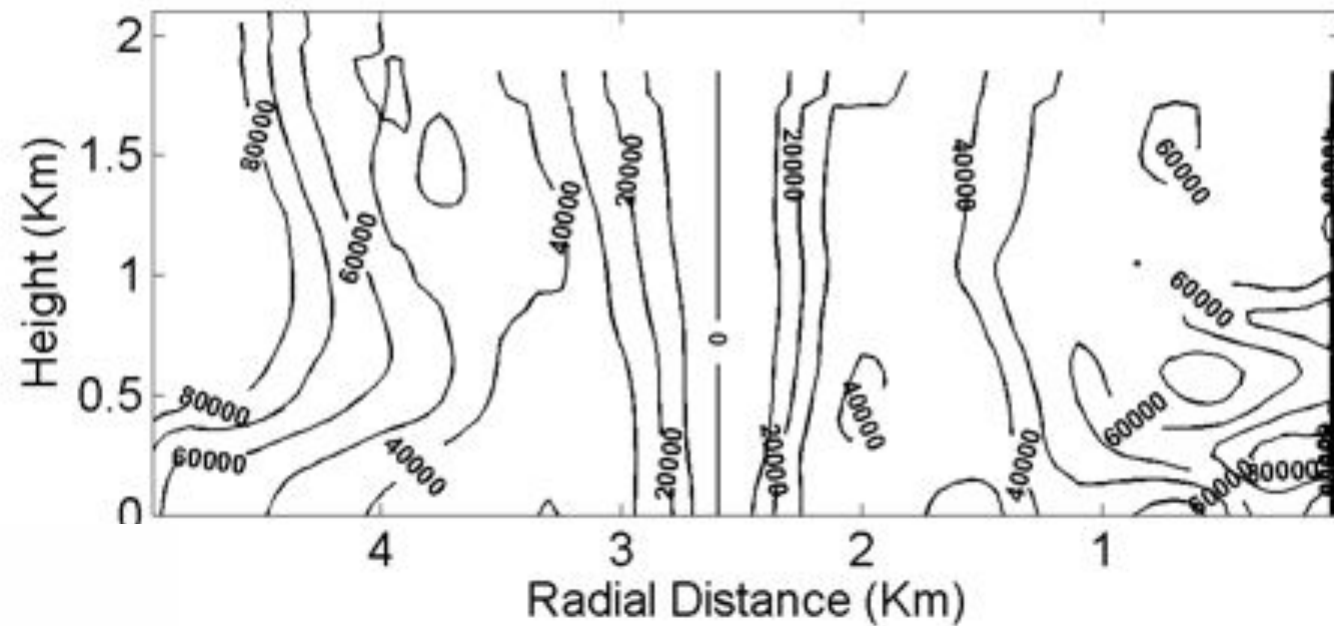
- X-Cs AT CONSTANT RANGE THROUGH CENTER OF TORNADO (*NOT* AZIMUTHALLY AVERAGED DATA)

COURTESY OF JANA HOUSER

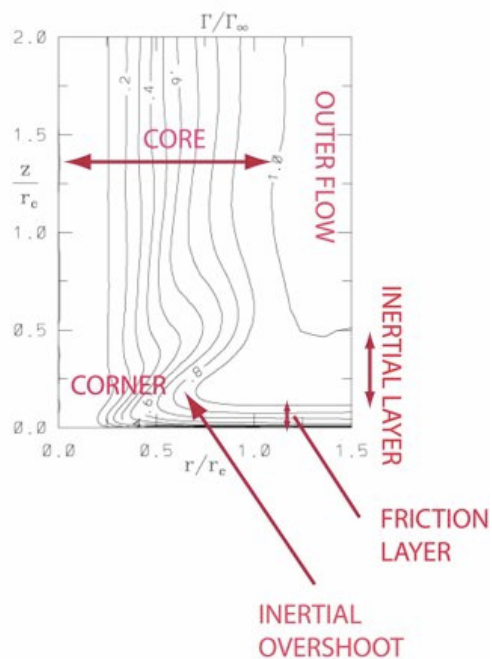
210223 SRV Contour at R=5km



210223 Angular Mom (m^2/s) at $R=5\text{km}$

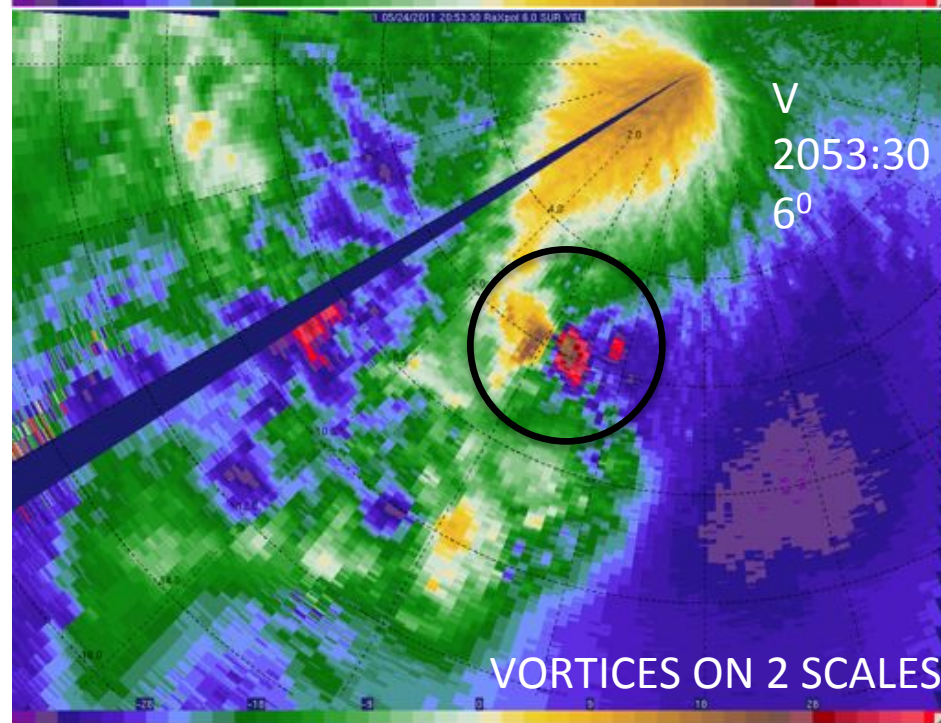
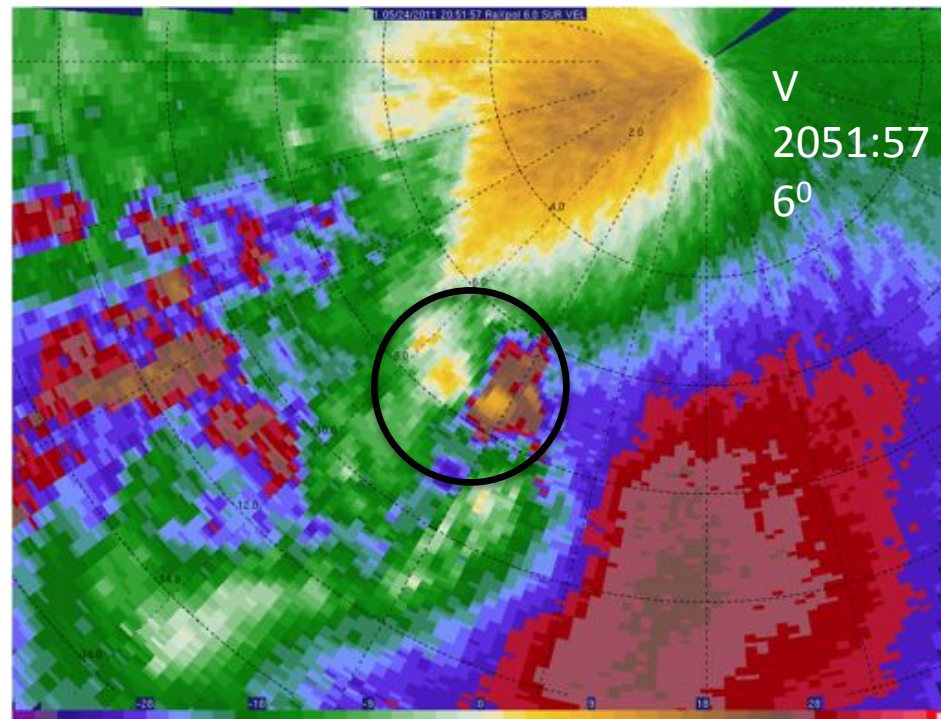
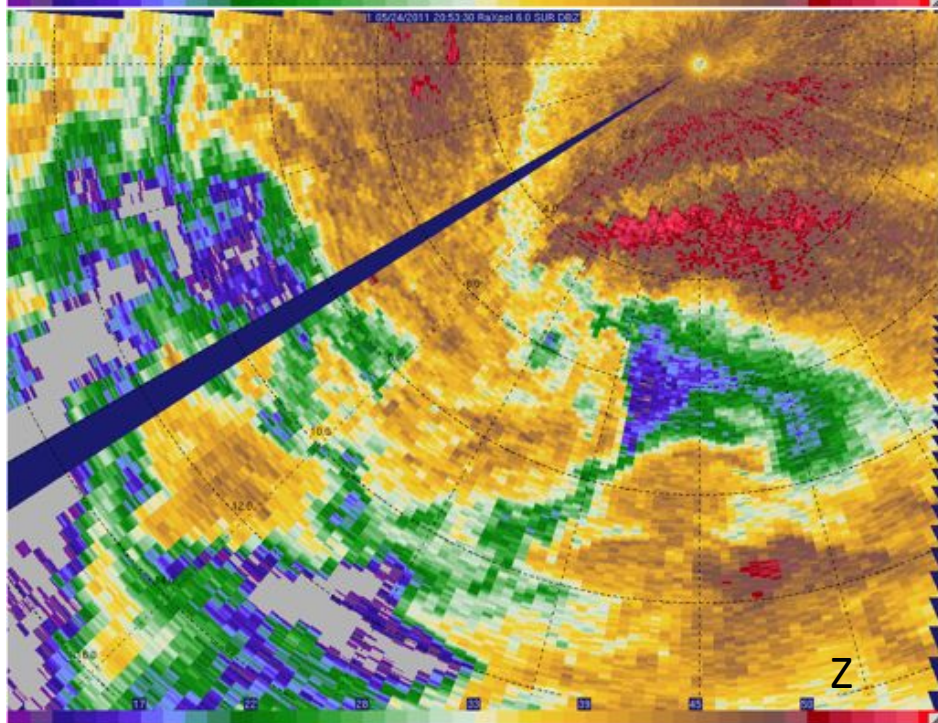
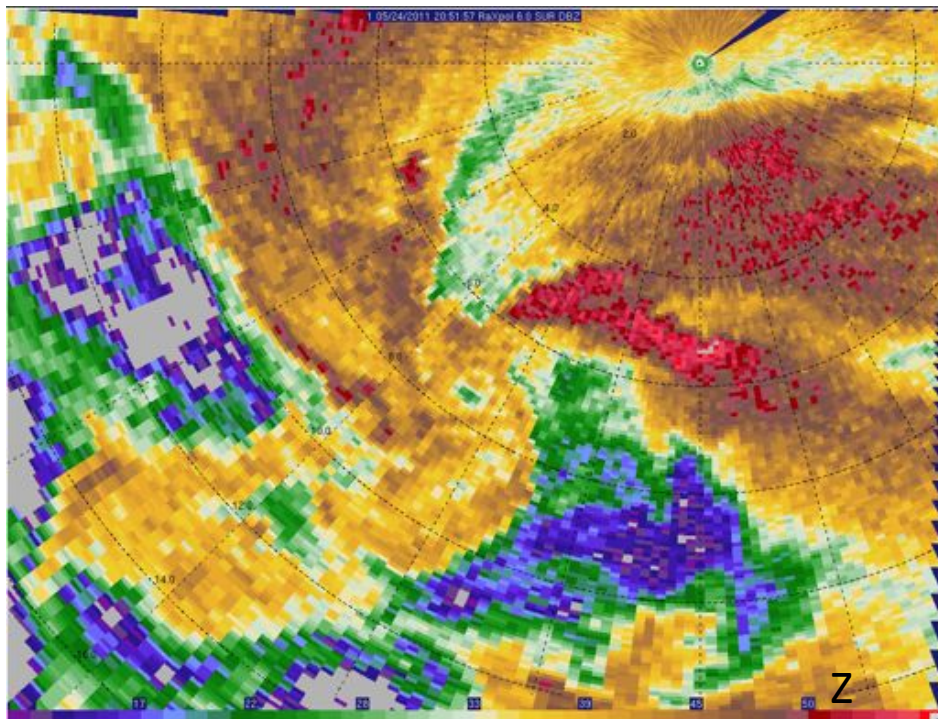


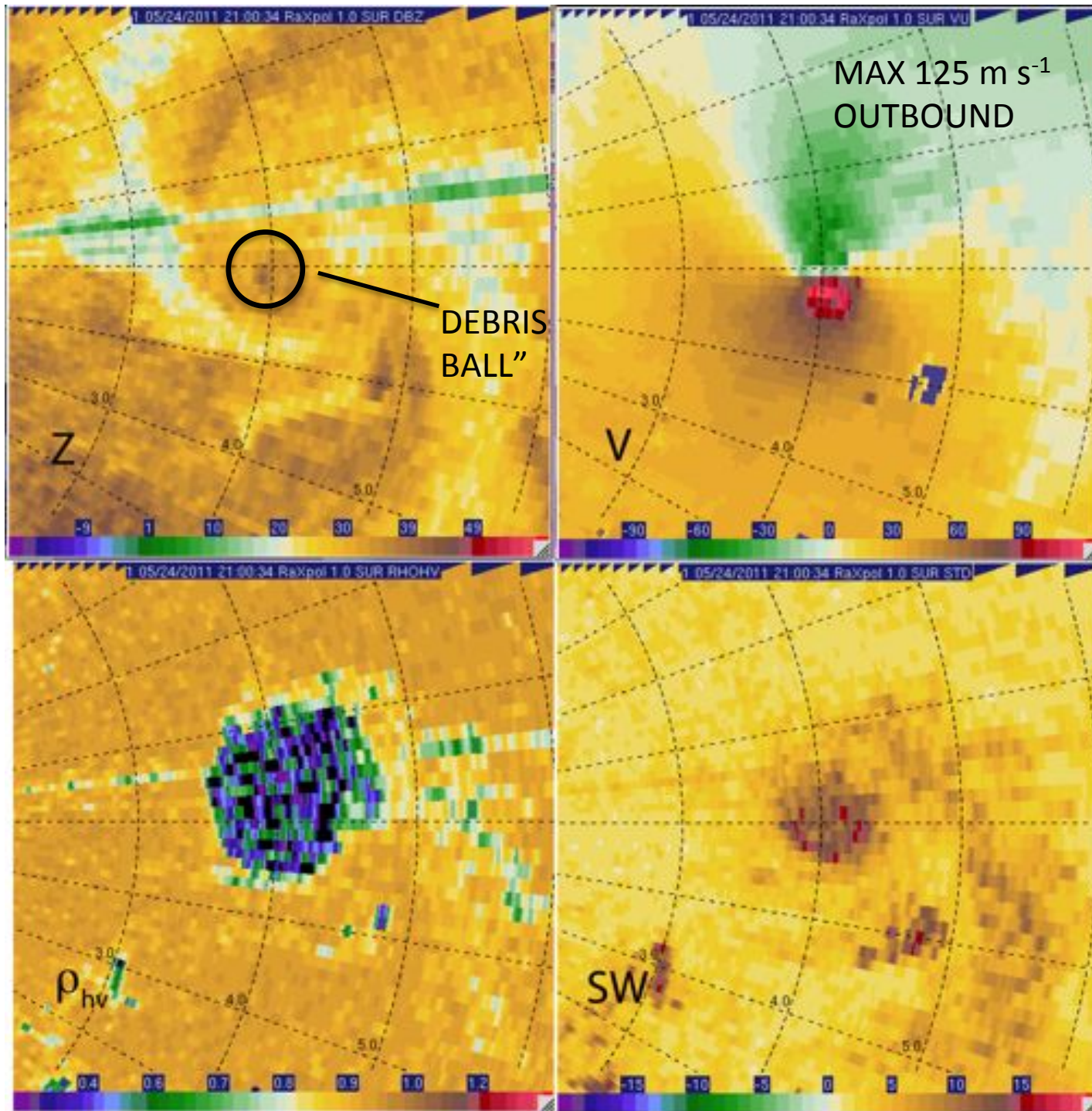
IDEALIZED
NUMERICAL
SIMULATION



- RADAR NOT “SEEING” SHALLOW FRICTION LAYER

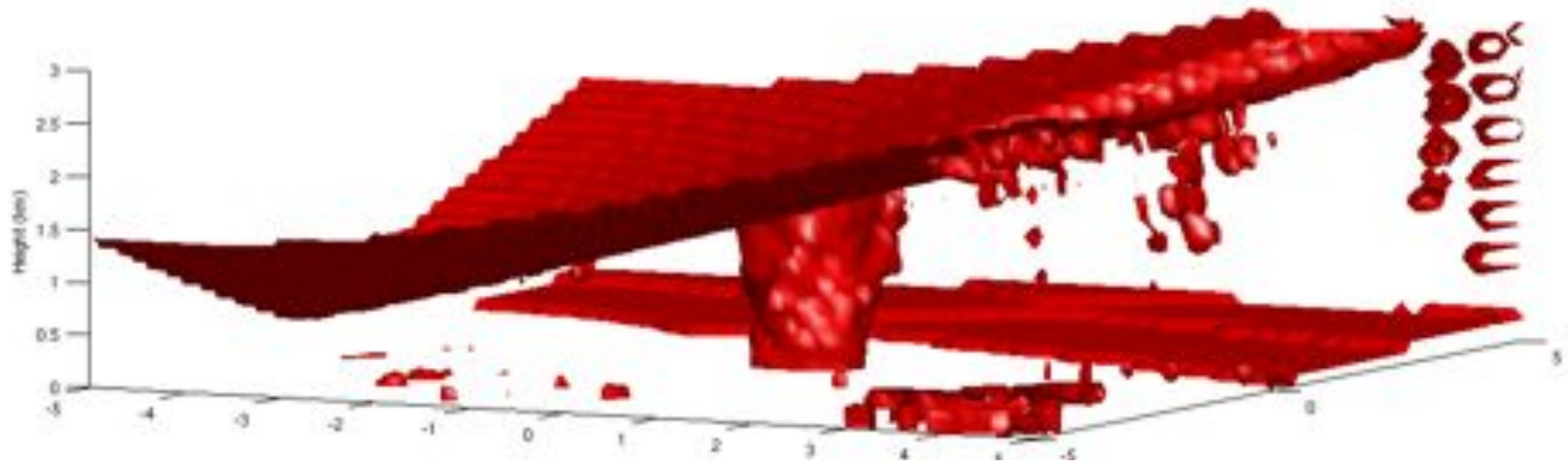
Based on an LES
by Lewellen et al. (2000)





DEBRIS CLOUD

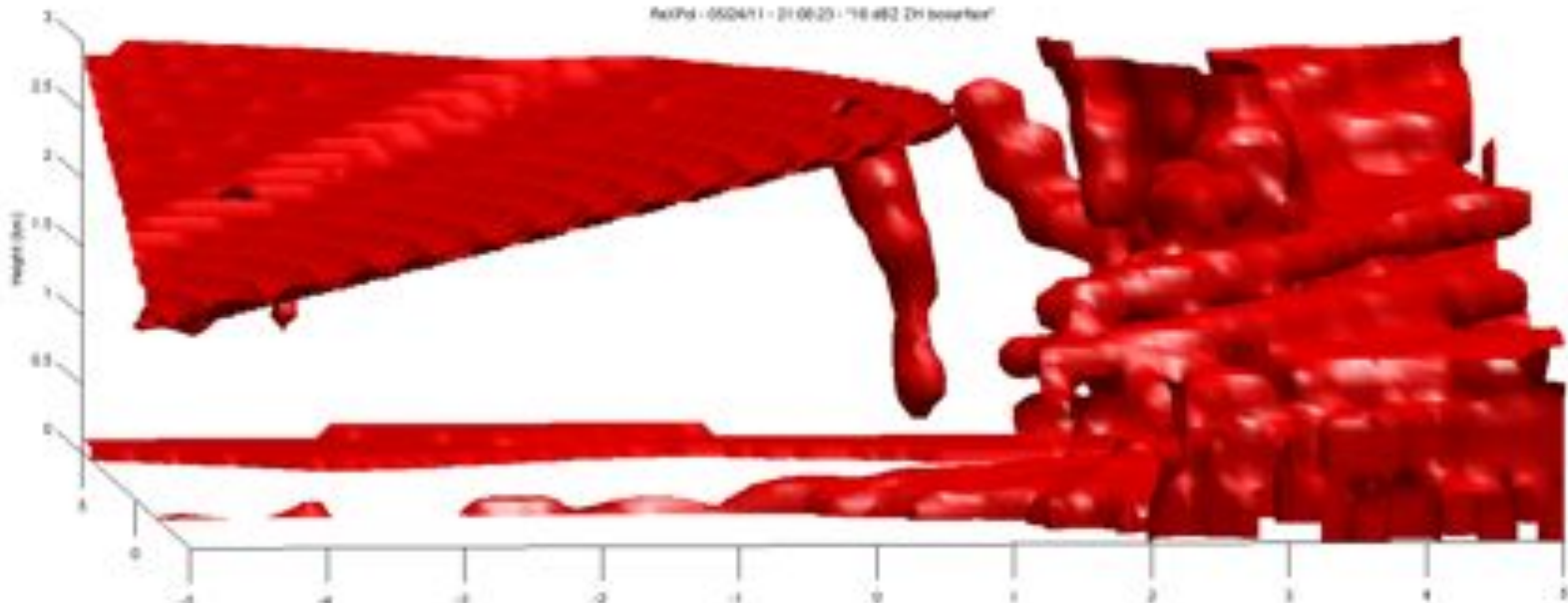
RaoPoi - El Reno Tornado - 21 02:22 UTC -- "0.80 [mchf]/ isosurface"



COURTESY OF JEFF SNYDER
USING MATLAB

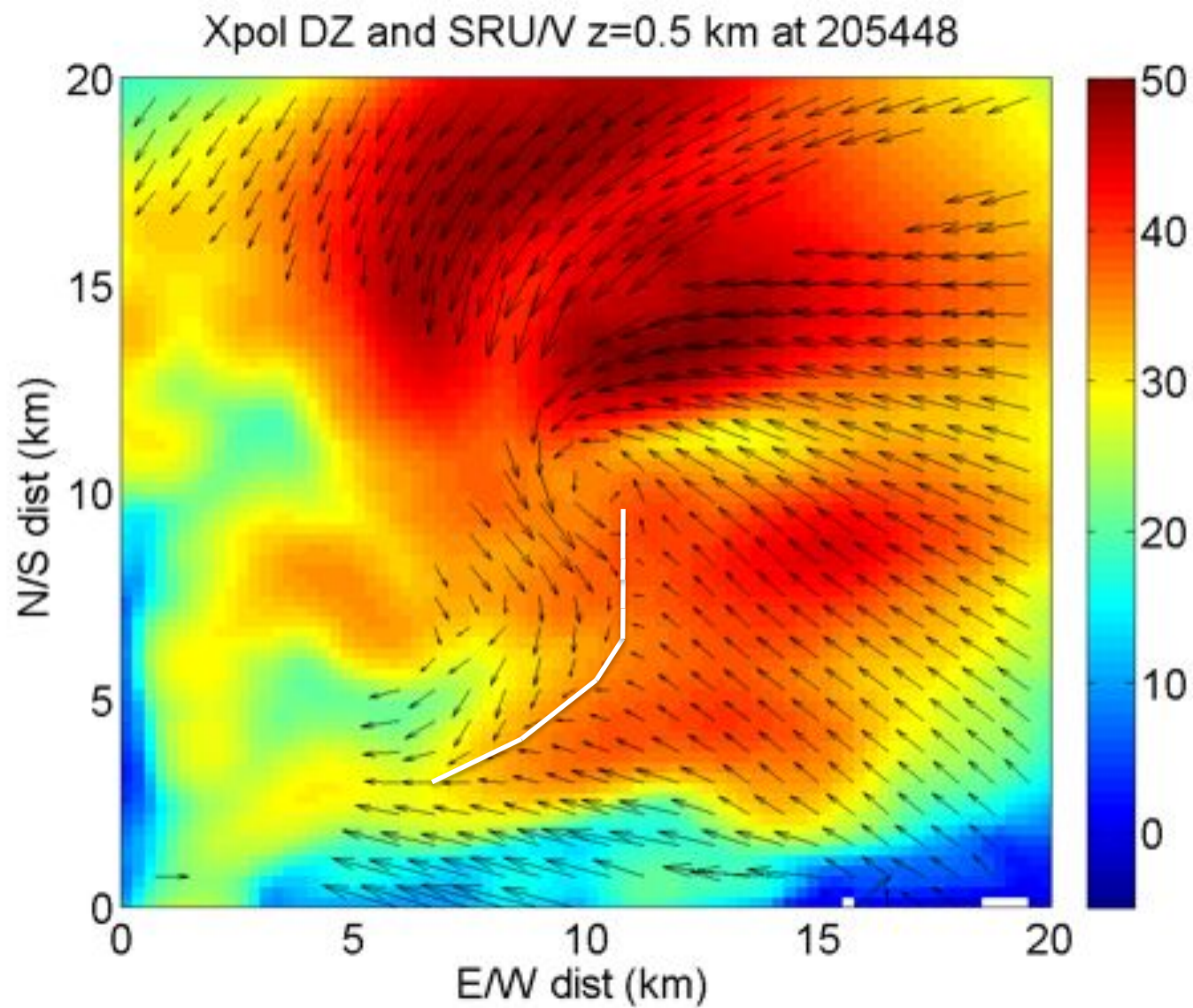
CONDENSATION FUNNEL

RaoPoi - 050411 - 21 06:25 - "1.8 dBZ 2m isosurface"









- BETWEEN-BEAM ANGLE $\sim 20^\circ$, SUB-OPTIMAL

COURTESY OF
JANA HOUSER



Data use subject to license.

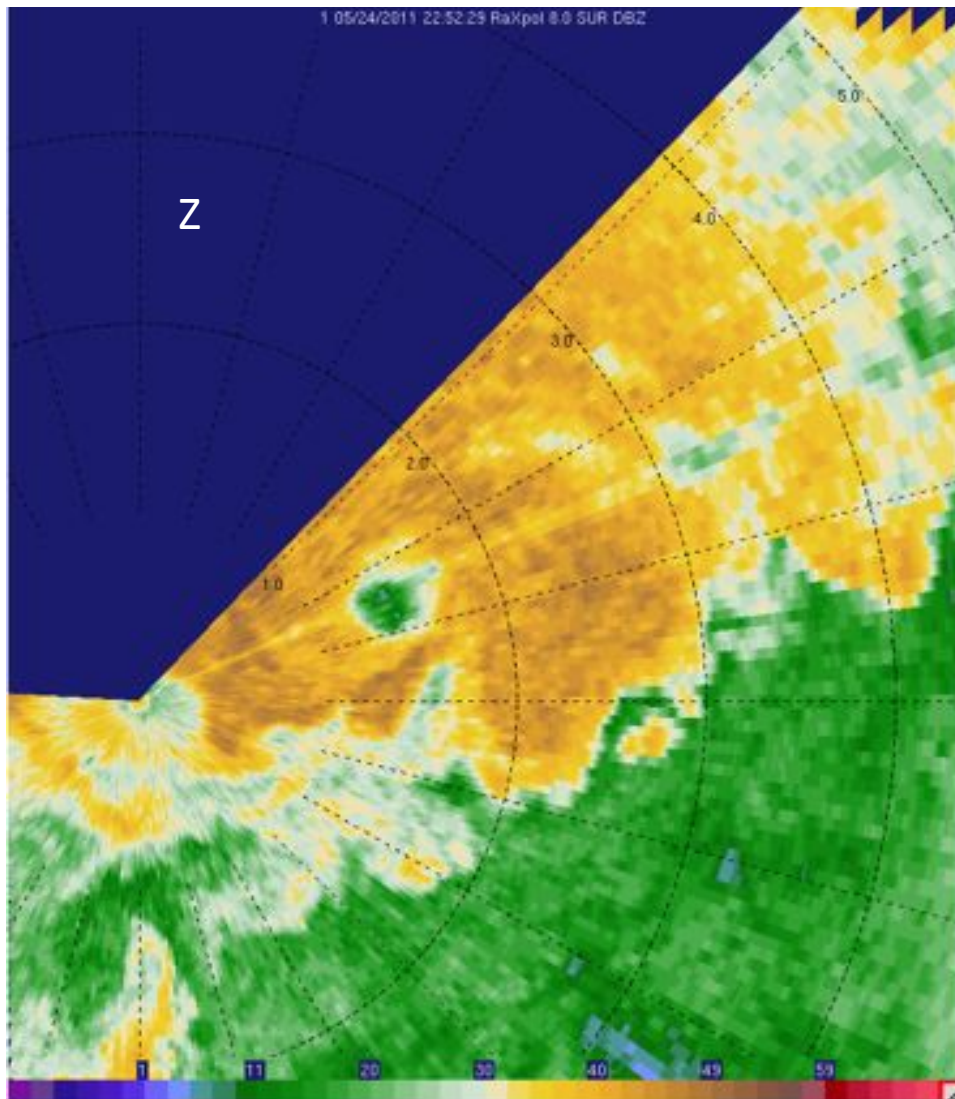
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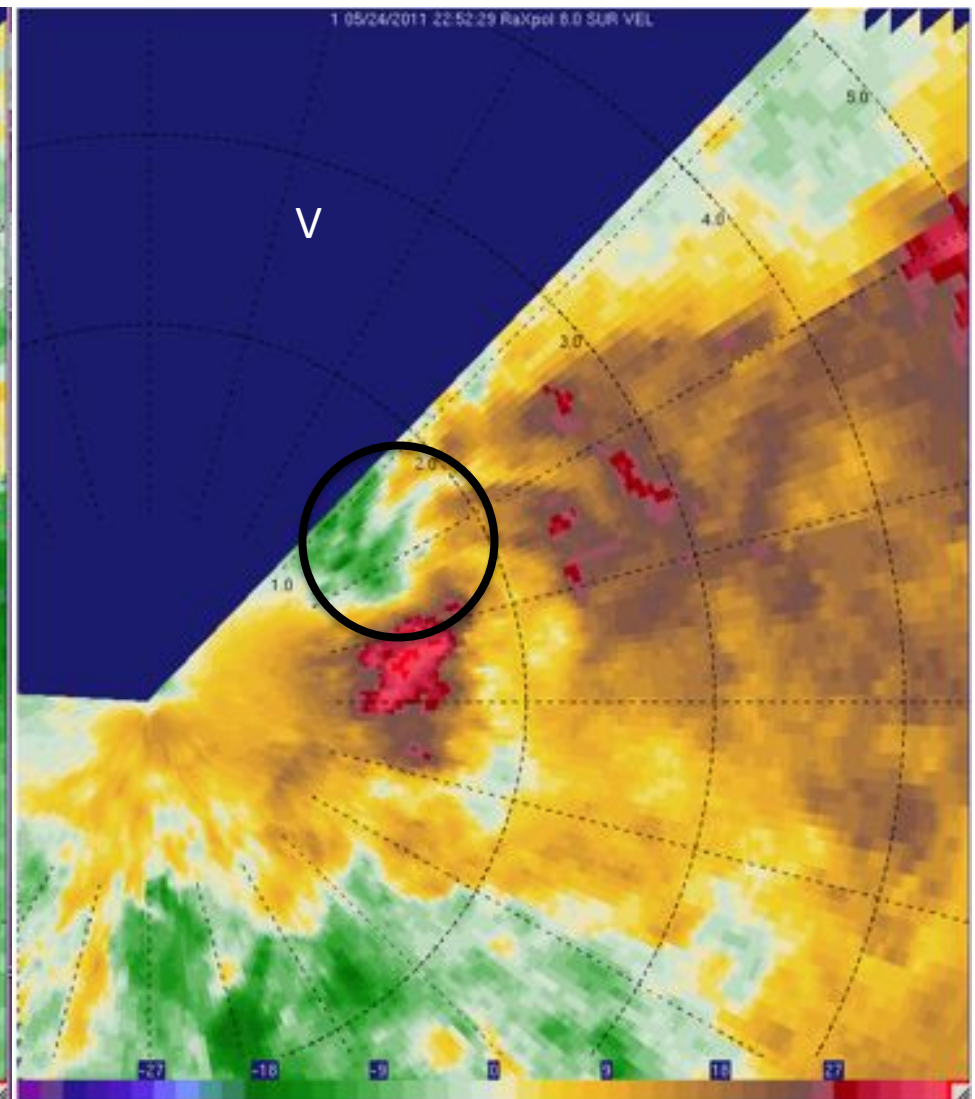


Data Zoom 11-5

COURTESY OF JEFF SNYDER



RaXPol
24 MAY 2011
2252:22 UTC



- SMALL-SCALE SHEAR SIGNATURES:
MULTIPLE VORTICES?

WORK TO BE DONE:

- ANALYSIS OF DATA FROM BOTH RAXPOL AND MWR-05XP

JANA HOUSER (FOCUS ON DOPPLER WIND DATA)

JEFF SYNDER (FOCUS ON POLARIMETRIC DATA)

- DOCUMENT TORNADOGENESIS ON STORM SCALE:
INNOVATIVE WAYS OF PROCESSING SINGLE-DOPPLER DATA
- DOCUMENT TORNADO STRUCTURE
- LOW-REFLECTIVITY ARC: NATURE OF? BOUNDARY-LAYER ROLL? LINE OF DESCENT
IN RFD?
- FUTURE SMALL FIELD EXPERIMENTS
ADVANTAGES: SUCCESS OVER LONG TERM AT LOW COST
DISADVANTAGES: NOT COMPREHENSIVE AS IN VORTEX2

FUNDING: NSF

ACKNOWLEDGMENTS: NSF GRANT AGS-0821231, MIKE FRENCH, JANA HOUSER (OU), JEFF SNYDER (OU), OTHER GRAD. STUDENTS (OU), RADAR COLLABORATORS(UMASS, NPS, ProSensing, OU)



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