Overview of a Rare Early Morning Tornadic QLCS Over East-Central Wisconsin on 2013 August 6-7

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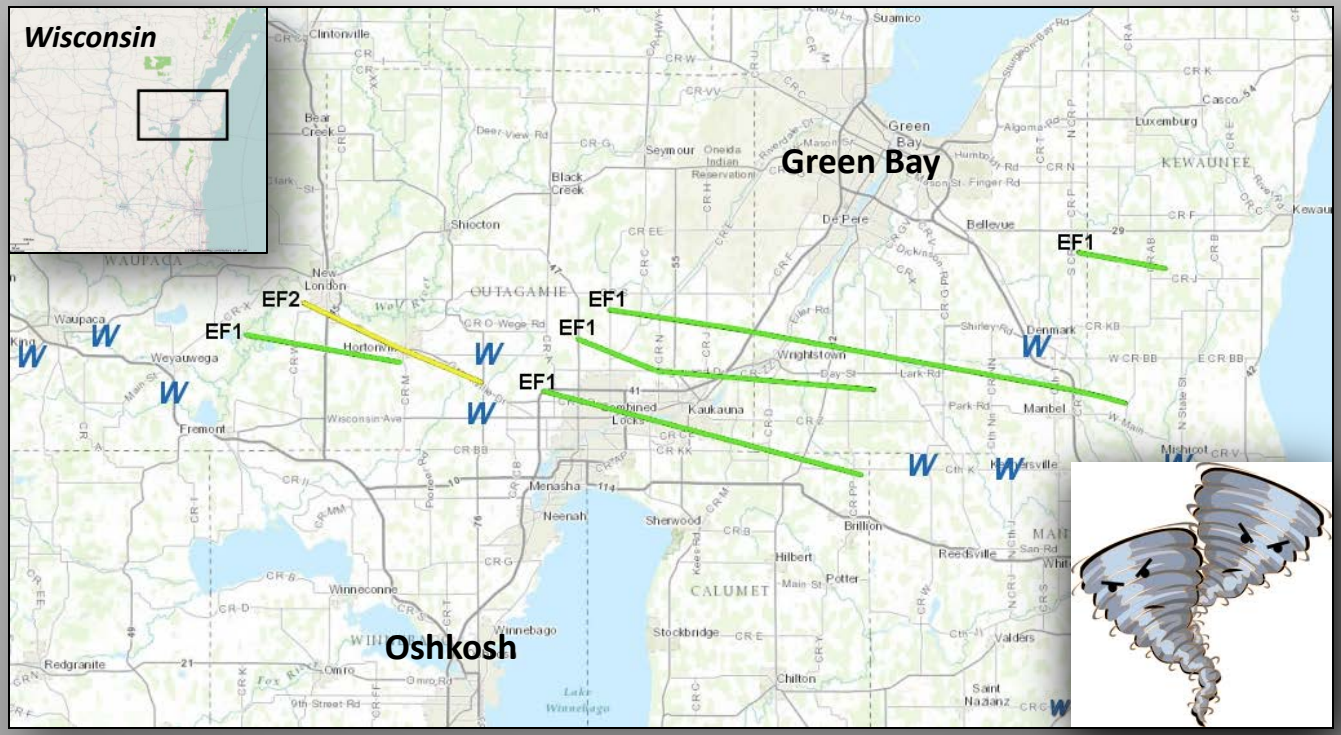
Introduction

Six tornadoes raced across the Fox Valley of east-central Wisconsin early in the morning of August 7, 2013.



Introduction

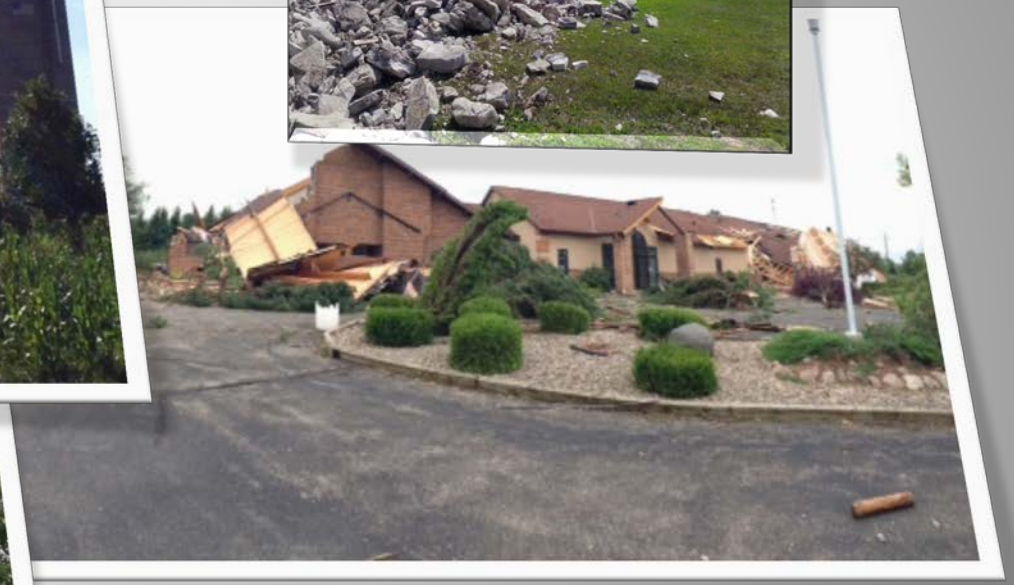
The first tornado developed just before 12:25 am CDT (0525 UTC); the final dissipated around 1:10 am – six tornadoes in about 45 minutes.

Climatologically rare event. Most early morning tornadoes in northeast Wisconsin since 1950.

The tornadoes were associated with a quasi-linear convective system – the tornadoes moved at nearly 65-70 mph.

Damage was near $20 million. Two minor injuries occurred at a campground.

Damage generally confined to narrow swaths and appeared to be associated with individual mesovortices embedded within the line. Little or no damage observed between narrow damage swaths.



- ✓ 250 houses sustained at least minor damage
- ✓ 100 businesses sustained at least minor damage
- ✓ Dozens of farmsteads were affected

Verification

All Severe Events & All Warnings

Warnings		Events		Scores			Lead Time (min)
Total	Verif	Total	Warned	POD	FAR	CSI	Initial
7	5	30	27	0.78	0.29	0.59	12.3

Tornado Events & Tornado Warnings Only

Warnings		Events (by county)		Scores			Lead Time (min)
Total	Verif	Total	Warned	POD	FAR	CSI	Initial
1	1	14	1	0.04	0.0	0.04	0.0

Source: NWS Verification Website

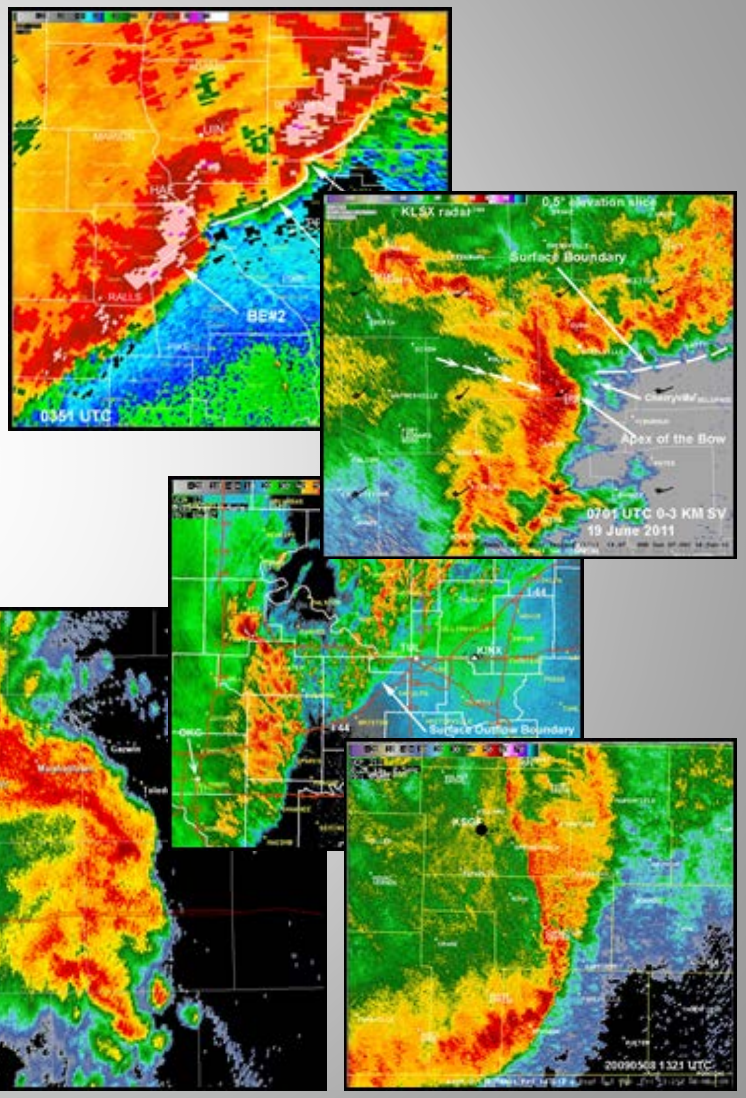
August 7, 2013 Tornadic QLCS

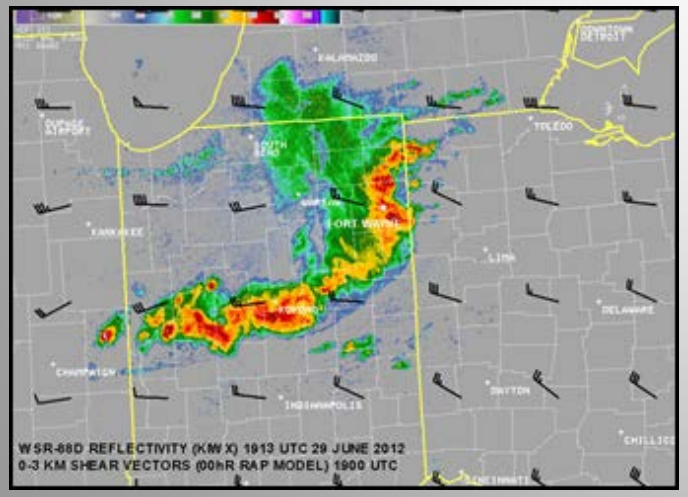
- **Introduction**
  - Damage and Impacts
  - Verification

- **Review of QLCS Structure & Dynamics**
- **Synoptic & Mesoscale Trends**
  - SPC and WFO Green Bay Expectations
- **Radar Evolution**
  - MCS Organization and Upscale Growth
  - Phase 1 – RIJ & Initial Mesovortex Development
  - Phase 2 – Tornadic Mesovortex Evolution
  - Dual Polarization – Tornado Debris Signatures (TDS)

QLCS Review

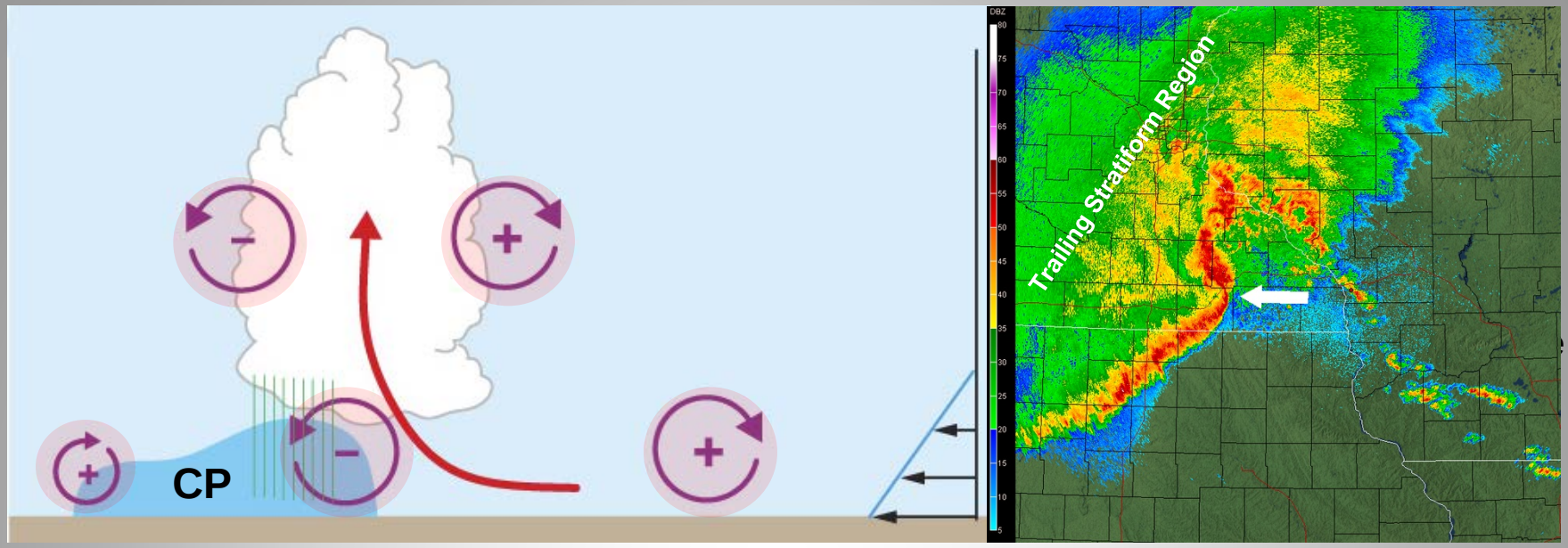
- **Q**uasi-**L**inear **C**onvective **S**ystem
- Primary Components of a well-organized QLCS:
  - Cold pool **(CP)**
  - Rear inflow Jet **(RIJ)**
  - Updraft/downdraft convergence zone **(UDCZ)**

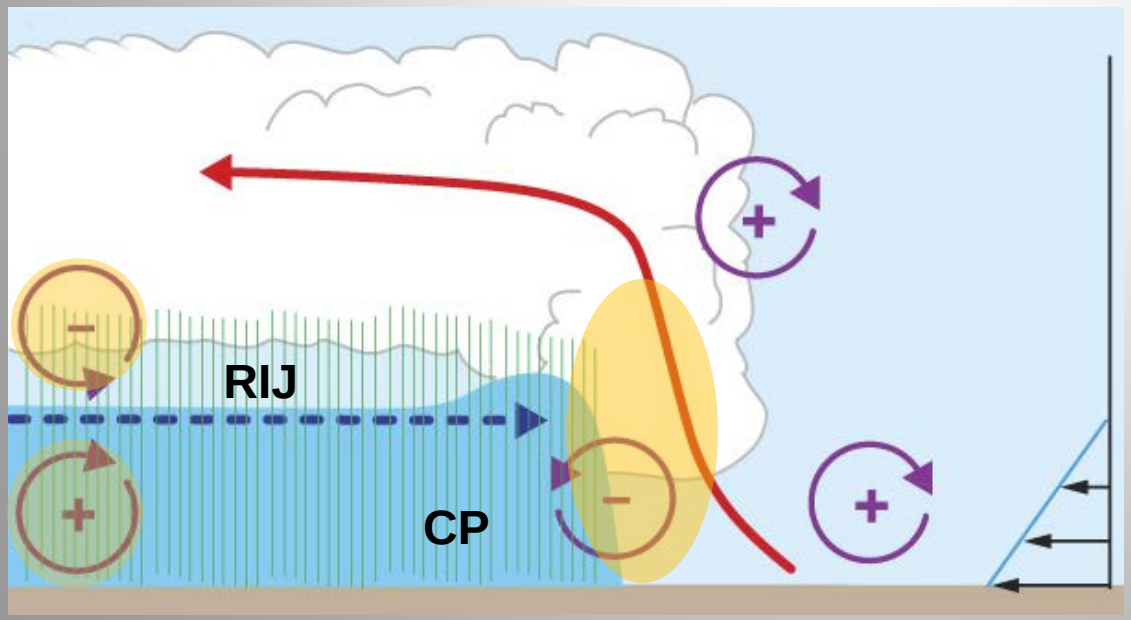




QLCS Review

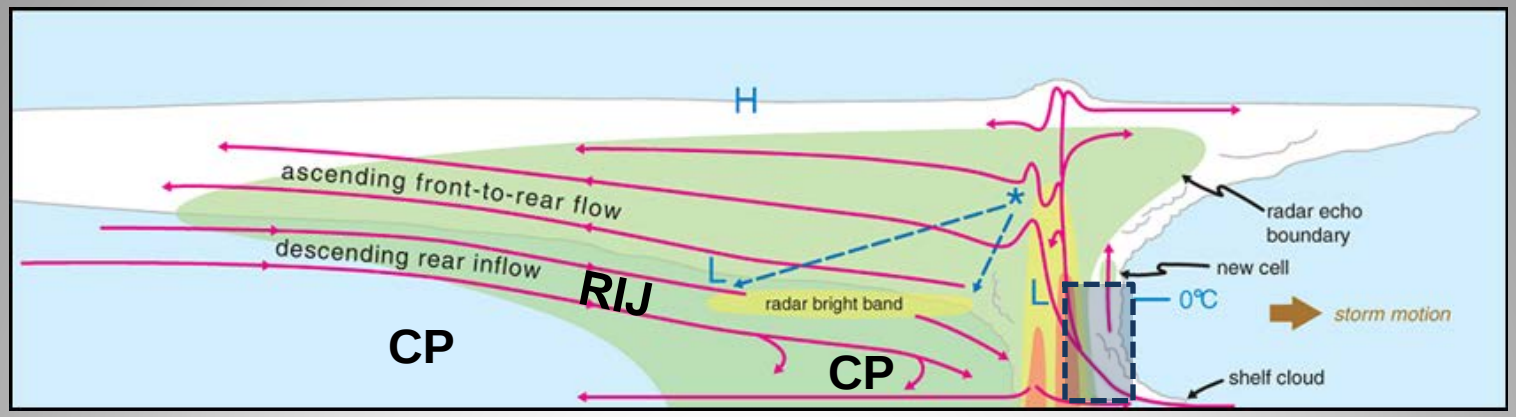
- Can produce damaging straight-line winds along leading gust front and/or tornadoes
  - **RIJ** or other localized outflow impinge on the leading edge. Enhances updraft locally and causes local acceleration/surge of the line (bow).
  - Strongest **mesovortices** typically develop in response to the line surge.
  - Most concentrated damage typically associated with mesovortices embedded along the leading edge (**UDCZ**).
  - Mesovortices may produce straight line wind damage or tornadoes.
  - Mesovortex tornadoes are typically shallow, have small diameters, genesis at lower-levels, develop both upwards and downward, spin-up very rapidly, short-lived. Sometimes evolve in families (episodes).
  - **Vortex stretching** important genesis mechanism.
  - Can be as strong as EF2/EF3 intensity.

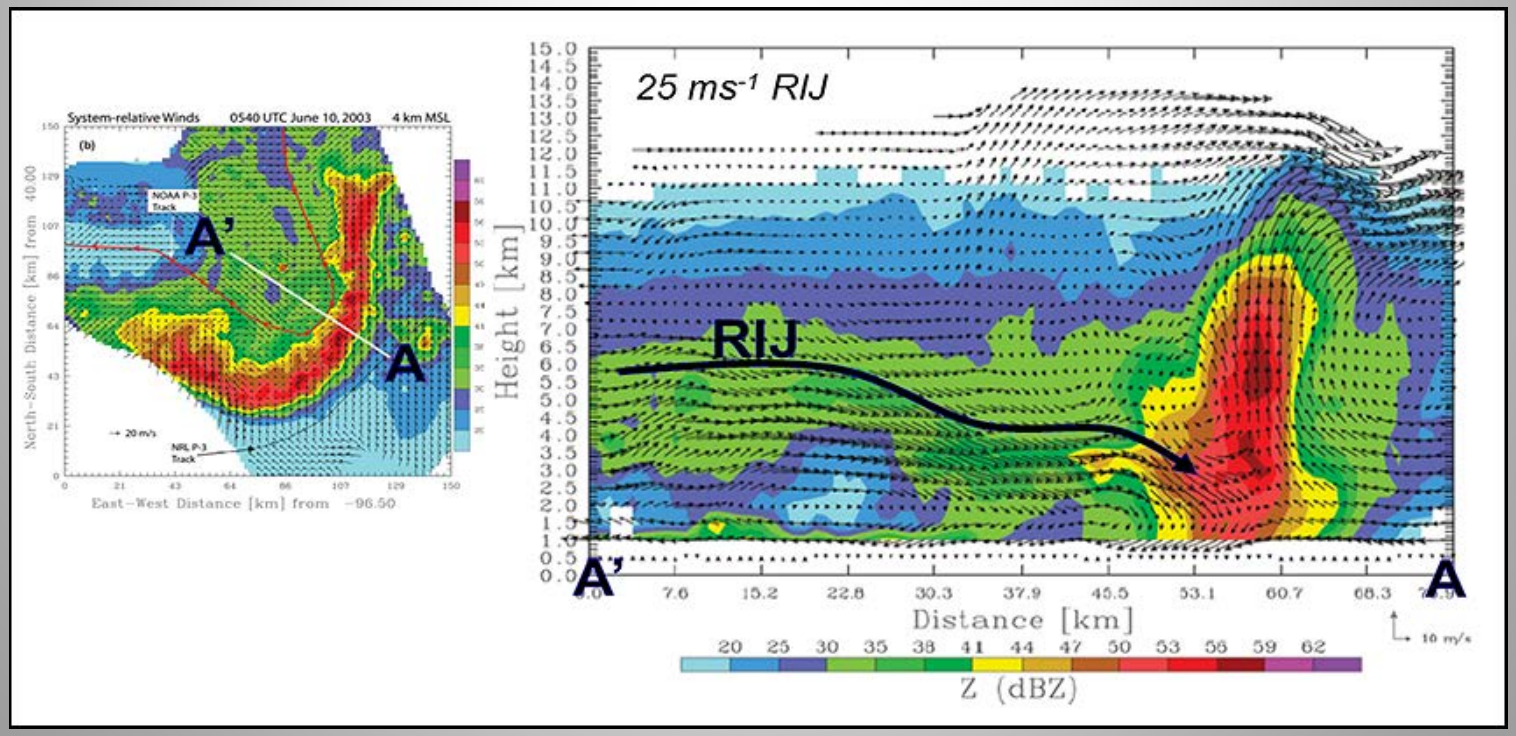


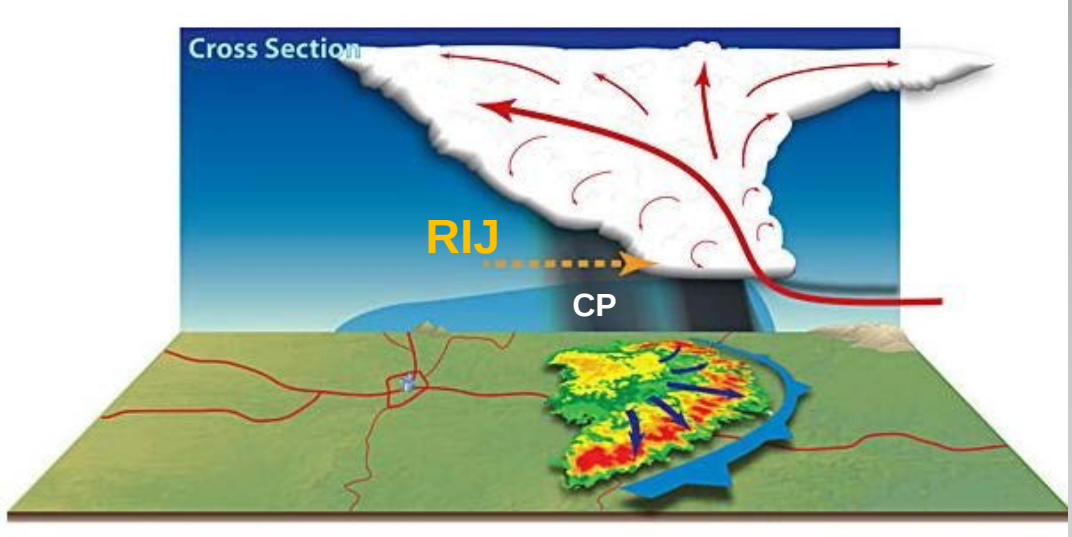


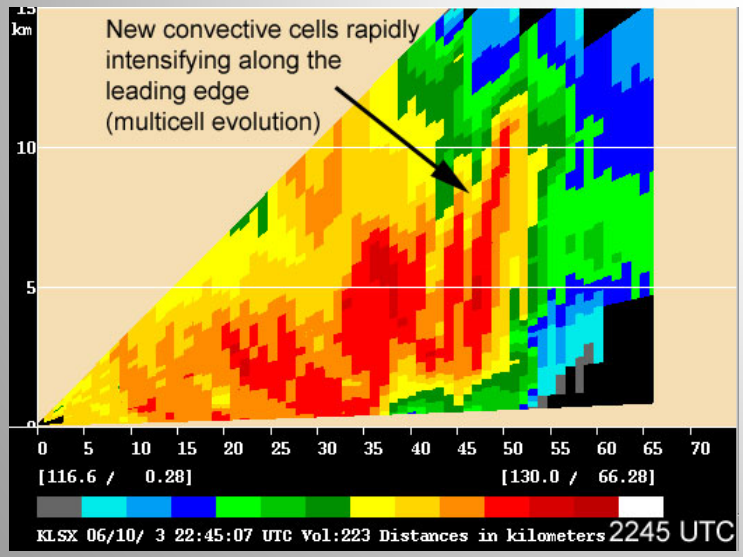
Horizontal vorticity associated with back edge (trailing stratiform region) of the developing MCS and back edge of developing cold pool act in concert to draw mid-level into the system forming the rear inflow jet **(RIJ)**.

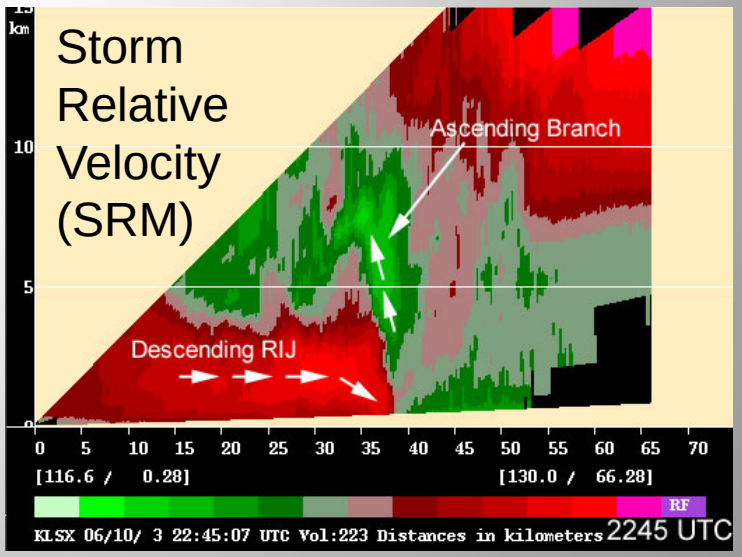
Area of convergence along the leading edge is referred to as the updraft-downdraft convergence zone **(UDCZ).**

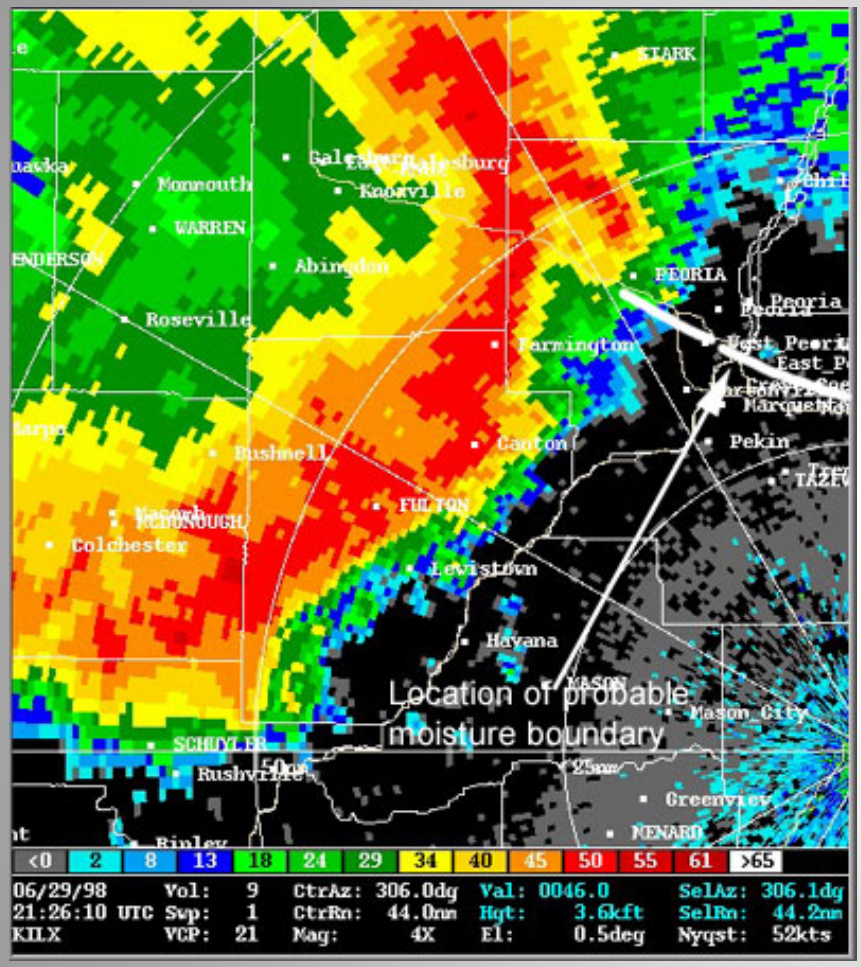

H
ascending front-to-rear flow
descending rear inflow
RIJ
L
radar bright band
L
CP
CP
radar echo boundary
new cell
0°C
storm motion
shelf cloud

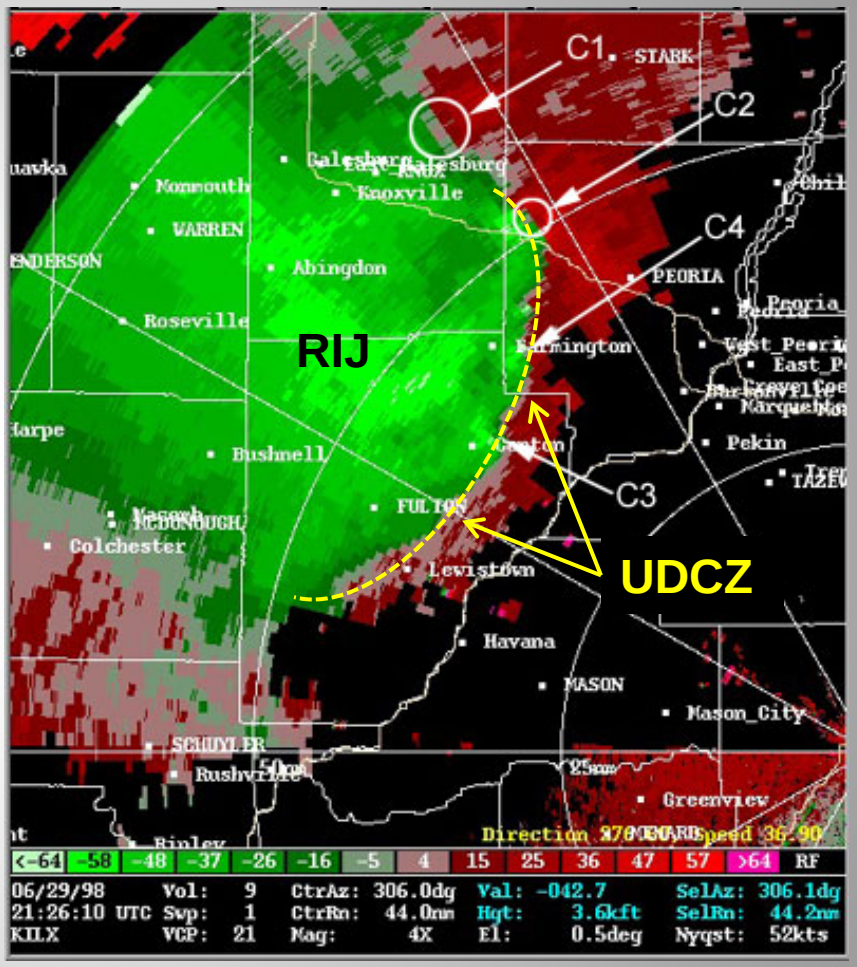

System-relative Winds
0540 UTC June 10, 2003
4 km MSL
(b)
NOAA P-3 Track
A'
A
20 m/s
NRL P-3 Track
North–South Distance [km] from 40.00
East–West Distance [km] from −96.50
25 ms-1 RIJ
RIJ
Height [km]
A'
A
Distance [km]
10 m/s
Z (dBZ)


Cross Section
RIJ
CP


New convective cells rapidly intensifying along the leading edge (multicell evolution)
km
10
5
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
[116.6 / 0.28]
[130.0 / 66.28]
KLSX 06/10/ 3 22:45:07 UTC Vol:223 Distances in kilometers
2245 UTC


Storm Relative Velocity (SRM)
Ascending Branch
Descending RIJ
km
10
5
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
[116.6 / 0.28]
[130.0 / 66.28]
RF
KLSX 06/10/ 3 22:45:07 UTC Vol:223 Distances in kilometers
2245 UTC



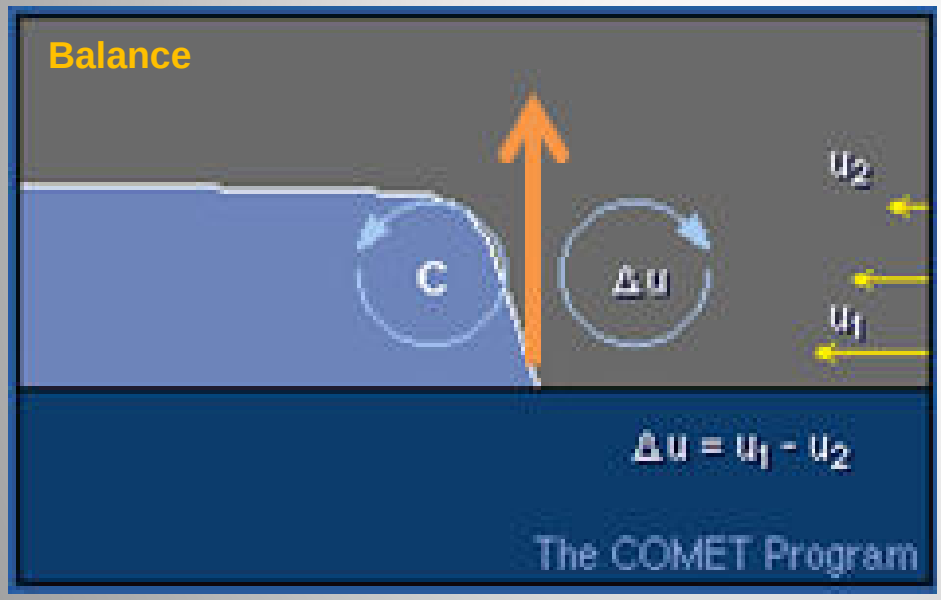


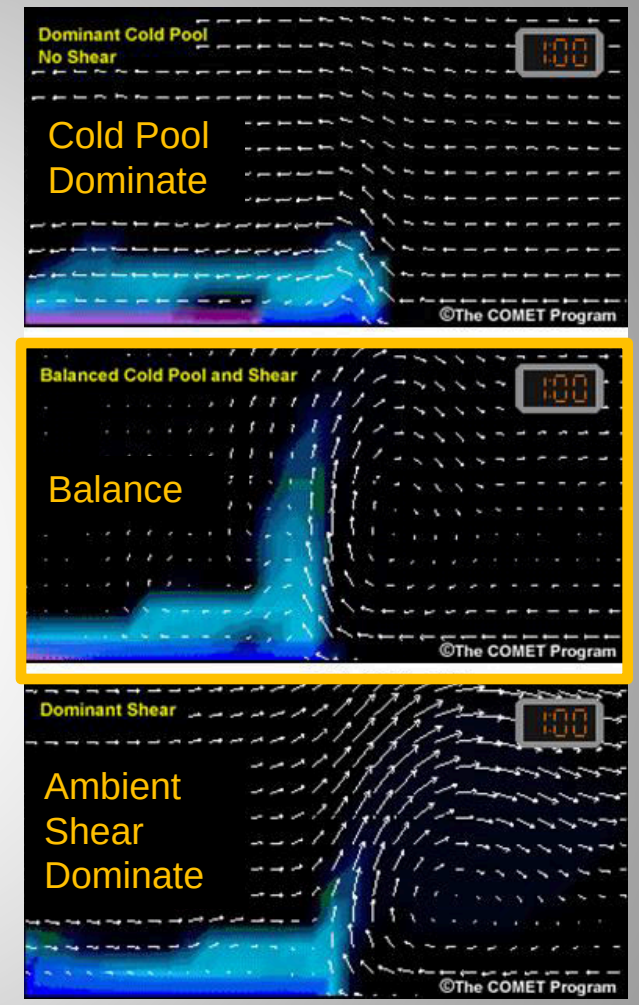
Mesovortex Tornadoes Typically Form Along the UDCZ

Balance is the Key

CP vs Ambient Shear

Promotes vertically erect updrafts and increased stretching potential





Weisman (1993)

How Can Balance Be Achieved along UDCZ?

Engerer et al (2008) did study of surface characteristics of observed cold pools (CP). He found that:

- ❑ The average CP depth is **3 km**
- ❑ The average maximum CP pressure rise is ~ **4.5 mb**

In a study by Rotunno, Klemp and Weisman (1998) it was shown that CP pressure rises (Δp) can be related to CP strength (c):

$$\left(2\frac{\Delta p}{\bar{\rho}}\right)^{1/2} \approx c$$

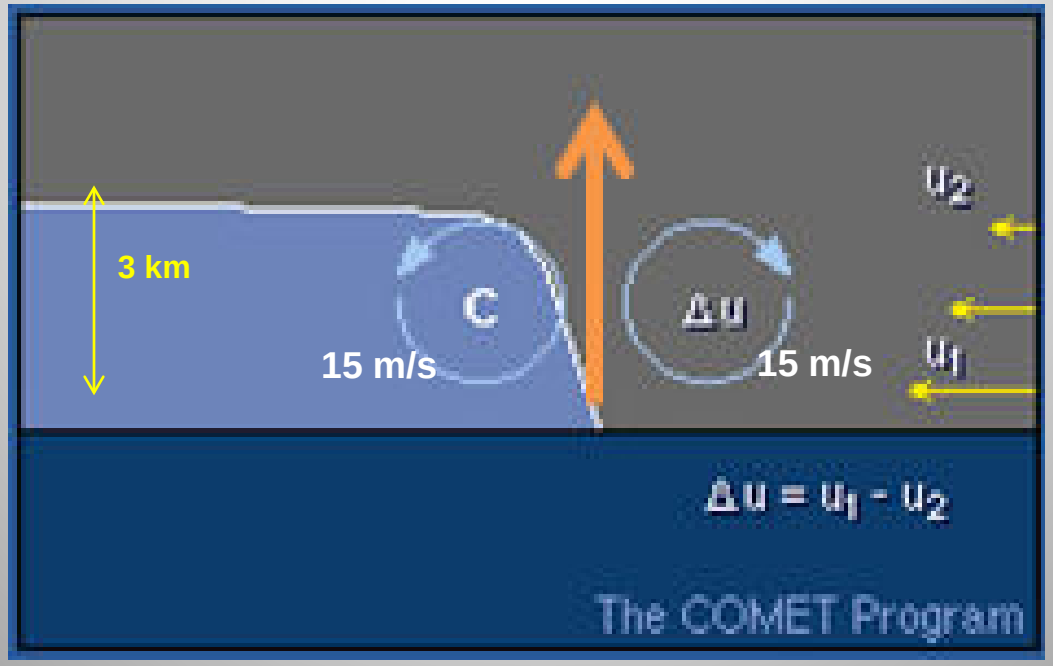
Units: (ms^{-1})

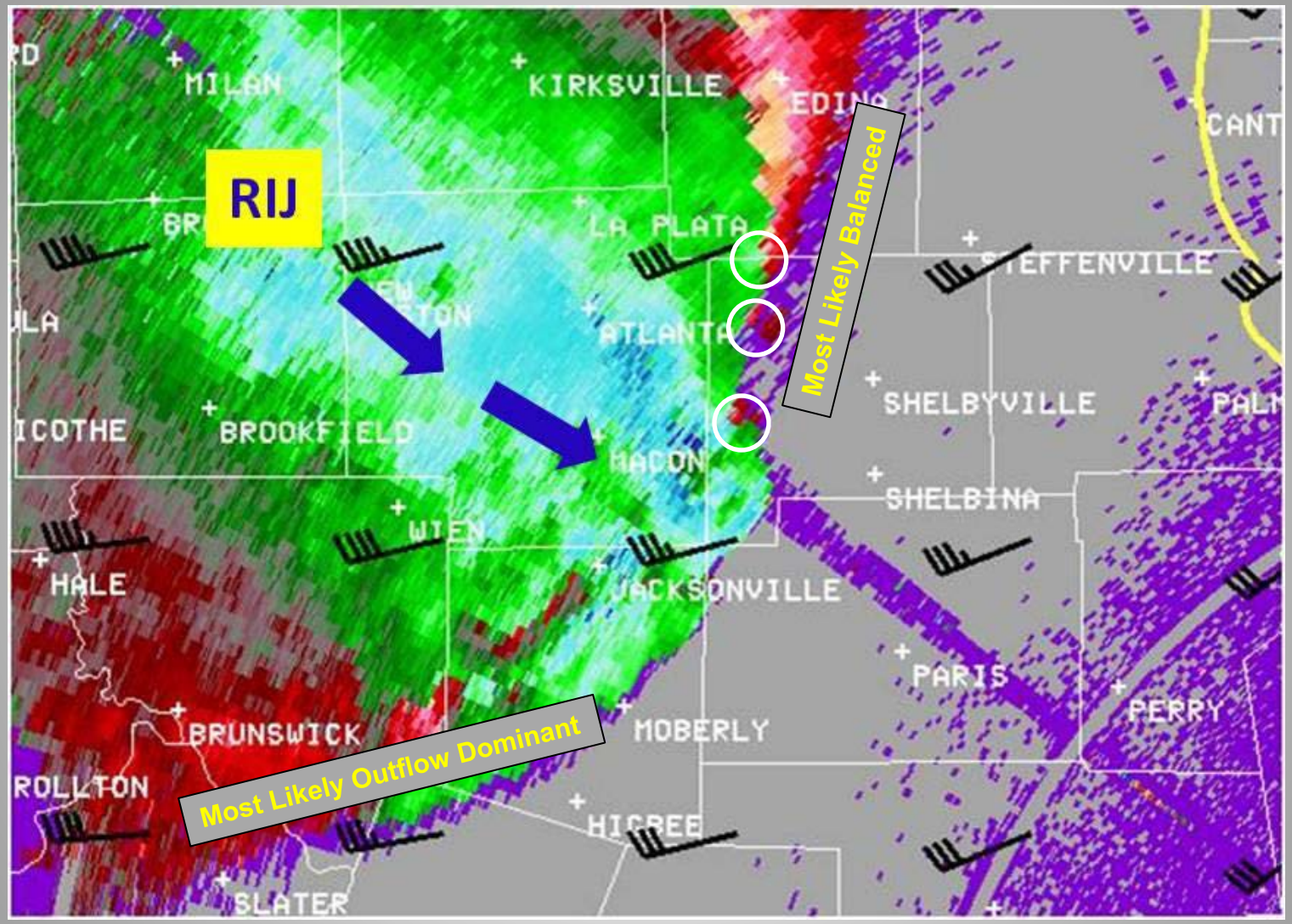
Given average CP (Δp) ~ 4.5 mb, average CP strength (c) is ~ 15 ms-1

Anticipating Mesovortex Genesis and Intensification

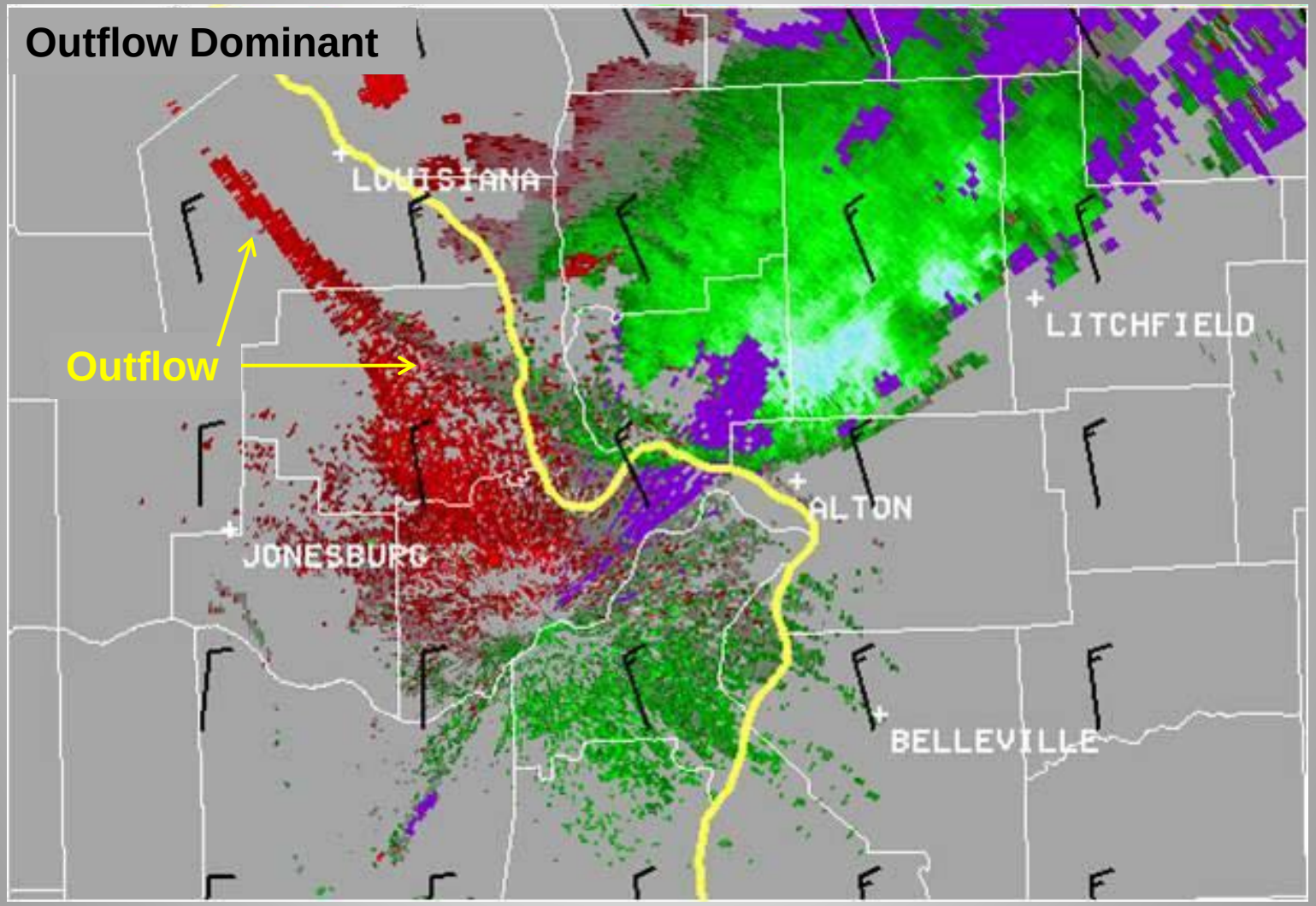
One key ingredient that Schaumann and Przybylinski (2012) found to be important for QLCS mesovortex genesis is **0-3 km** bulk shear values (ambient environment) **≥ 15 m/s (30 kts).**

This threshold should make some sense as it is represents the amount of ambient environmental shear that would be required to balance a typical cold pool.





RAP 0-3 Bulk Shear Vectors and 0.5 Degree Radar Reflectivity



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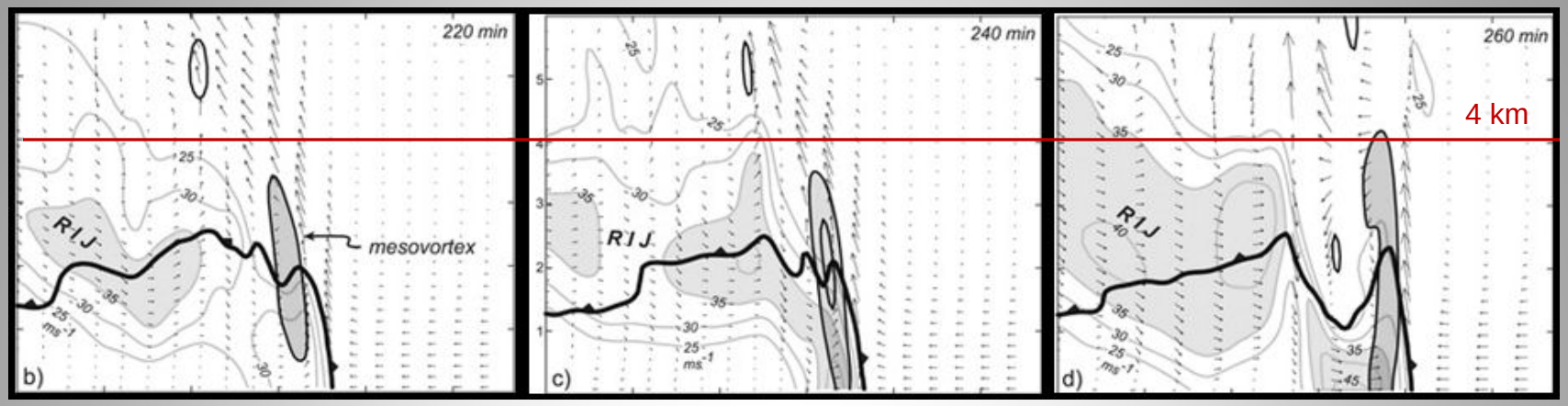
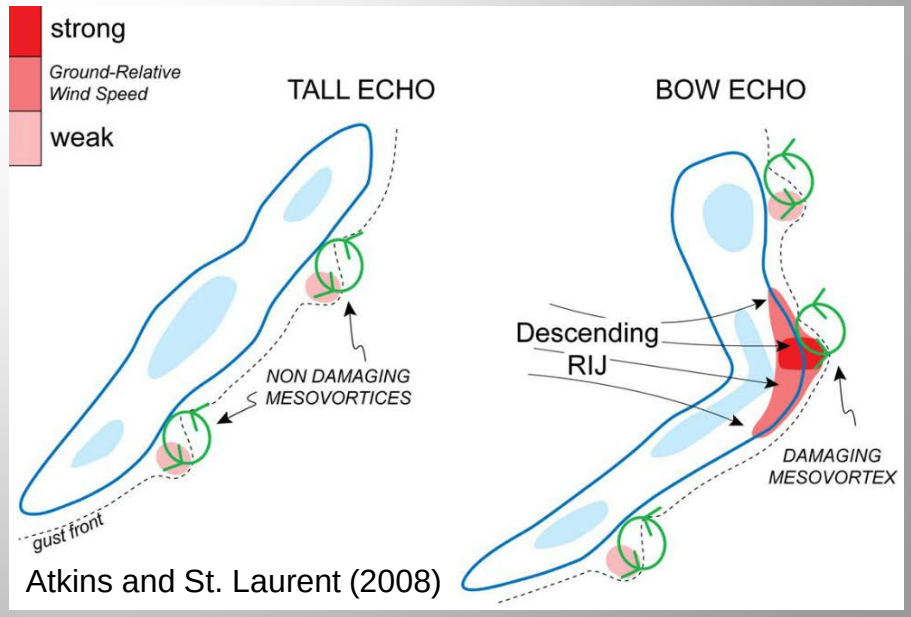
Anticipating Mesovortex Genesis and Intensification



Mesovortices intensify rapidly as RIJ impinges on leading UDCZ. Enhances updraft and stretching.

Mesovortex can become quite deep. Depths to 6 km have been documented.

Strongest/most damaging located near or just north of the apex.

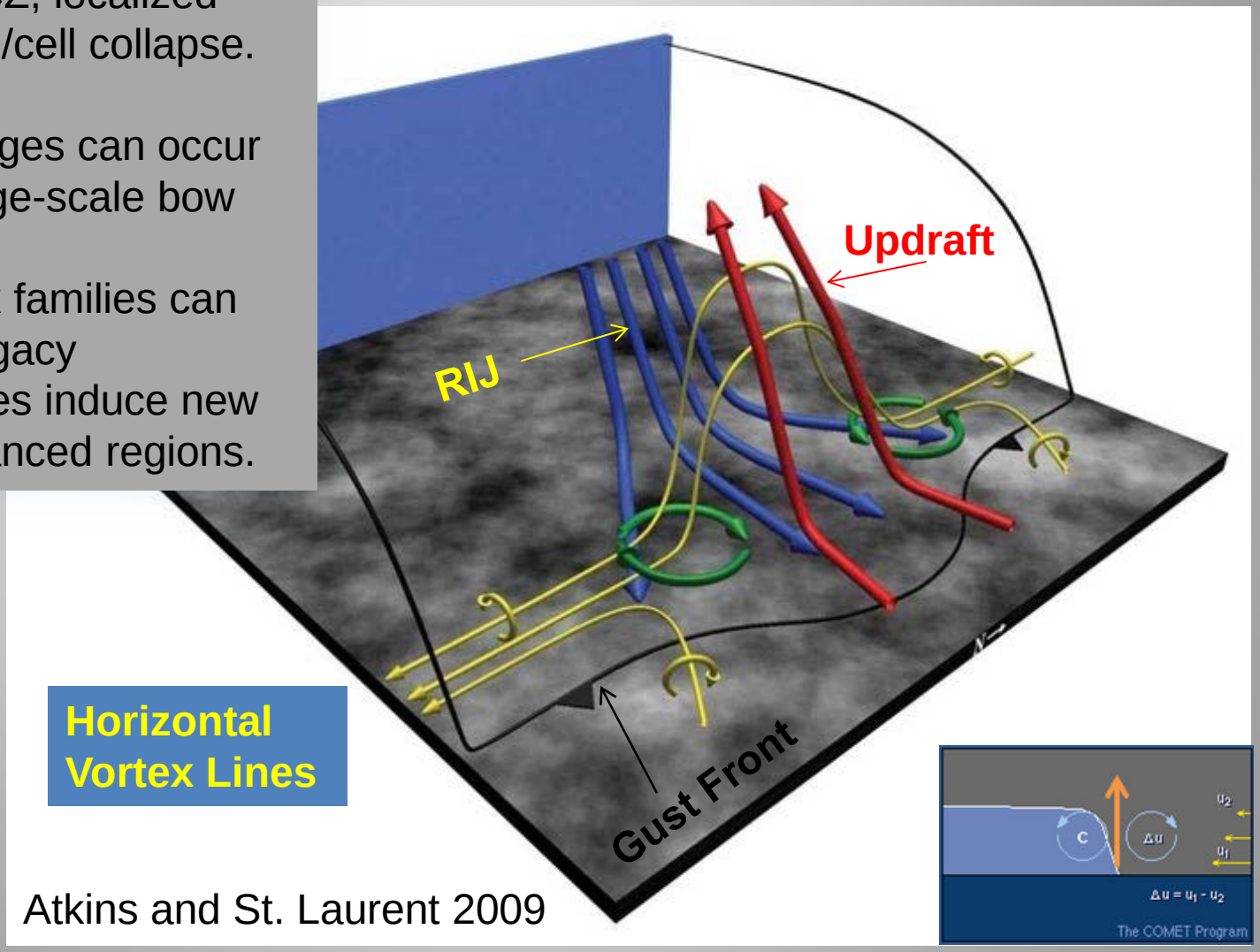


Atkins and St. Laurent (2008)

Bow Echo/Surge can be caused by RIJ impinging on the UDCZ, localized microbursts/cell collapse.

Several surges can occur within a large-scale bow

Mesovortex families can occur as legacy mesovortices induce new surges/balanced regions.



Atkins and St. Laurent 2009

Summary

- ✓ Main components of a well-organized QLCS include the **cold pool (CP), rear inflow jet (RIJ)** and **updraft-downdraft convergence zone (UDCZ)**.

- ✓ Mesovortex tornadoes form along the leading edge (UDCZ) of the QLCS. **UDCZ is a source region for horizontal vorticity.**

- ✓ **<u>Balance</u>** between the CP and environmental shear important for mesovortex genesis and intensification along the UDCZ. Maintains erect updrafts that can later be stretched.

- ✓ Ascent along the UDCZ can force parcels to their LFC ("**forced ascent**") in stable environments (e.g. nocturnal stabilization >> SBCIN present). **QLCS tornadoes observed with SBCIN < -200 J/kg.**

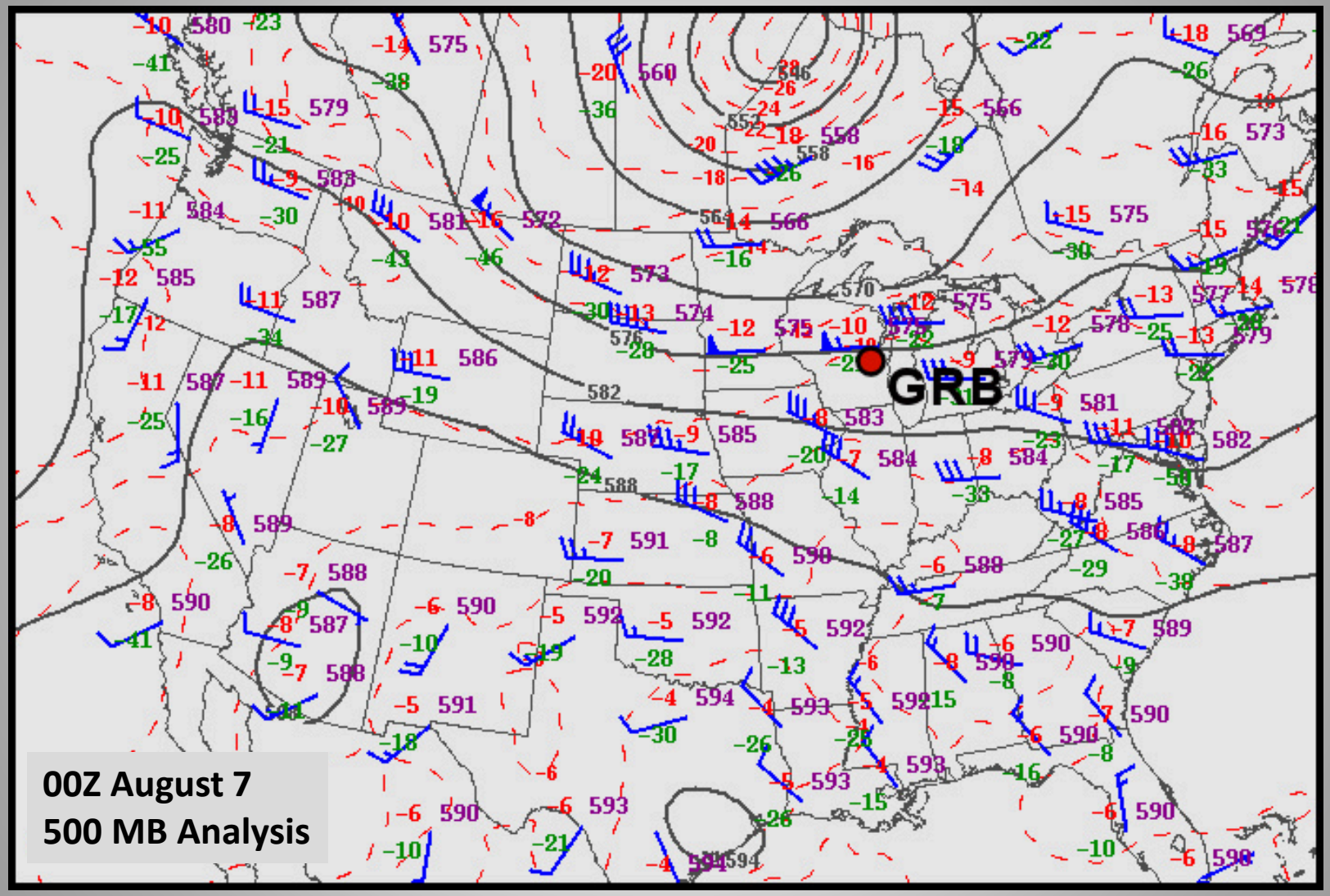
- ✓ 0-3 km (line normal) bulk shear **> 15 ms^{-1} (30 kts)** favors mesovortex genesis. This amount of ambient shear represents that **required to balance "typical" CP shear**.

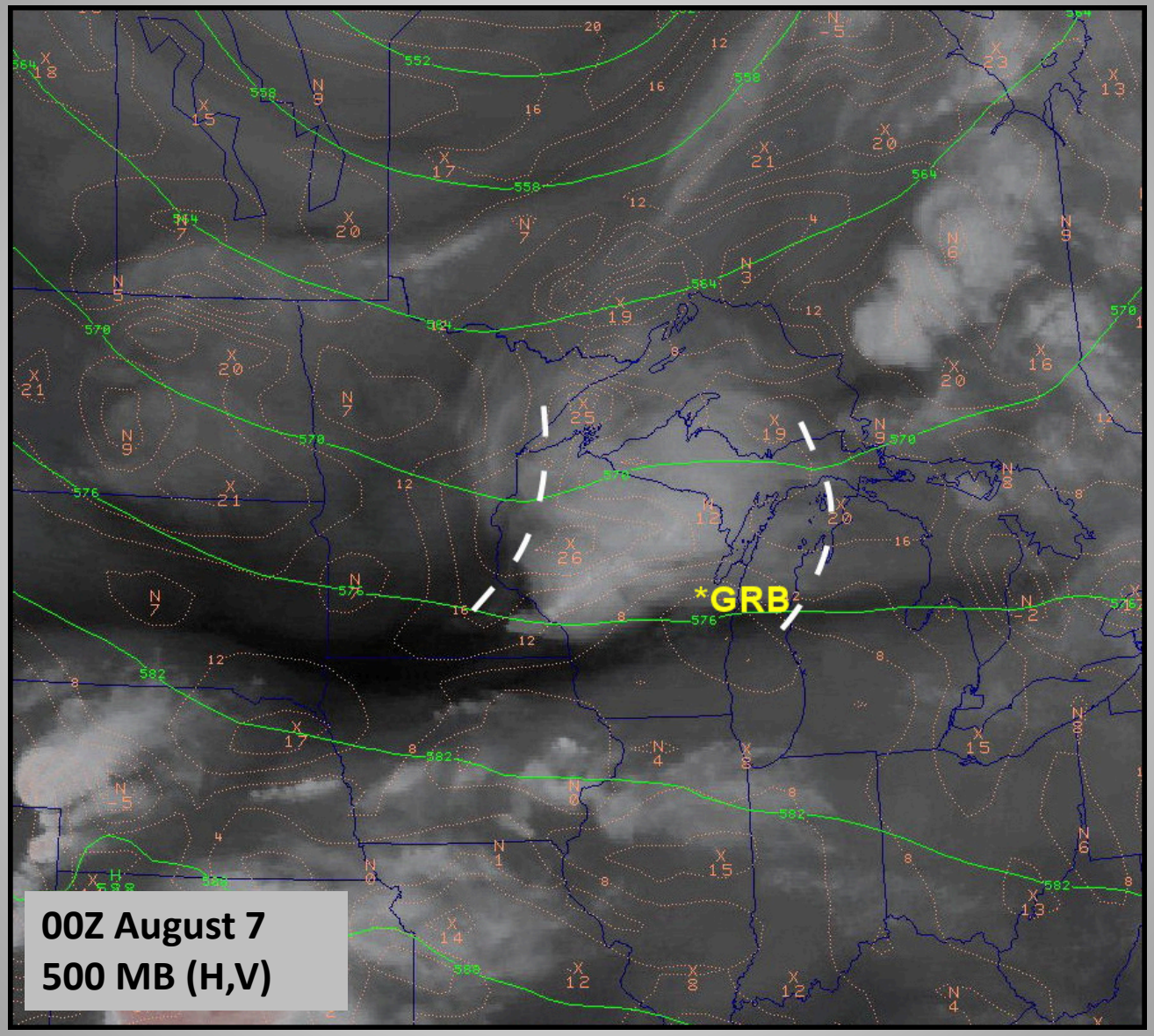
Summary

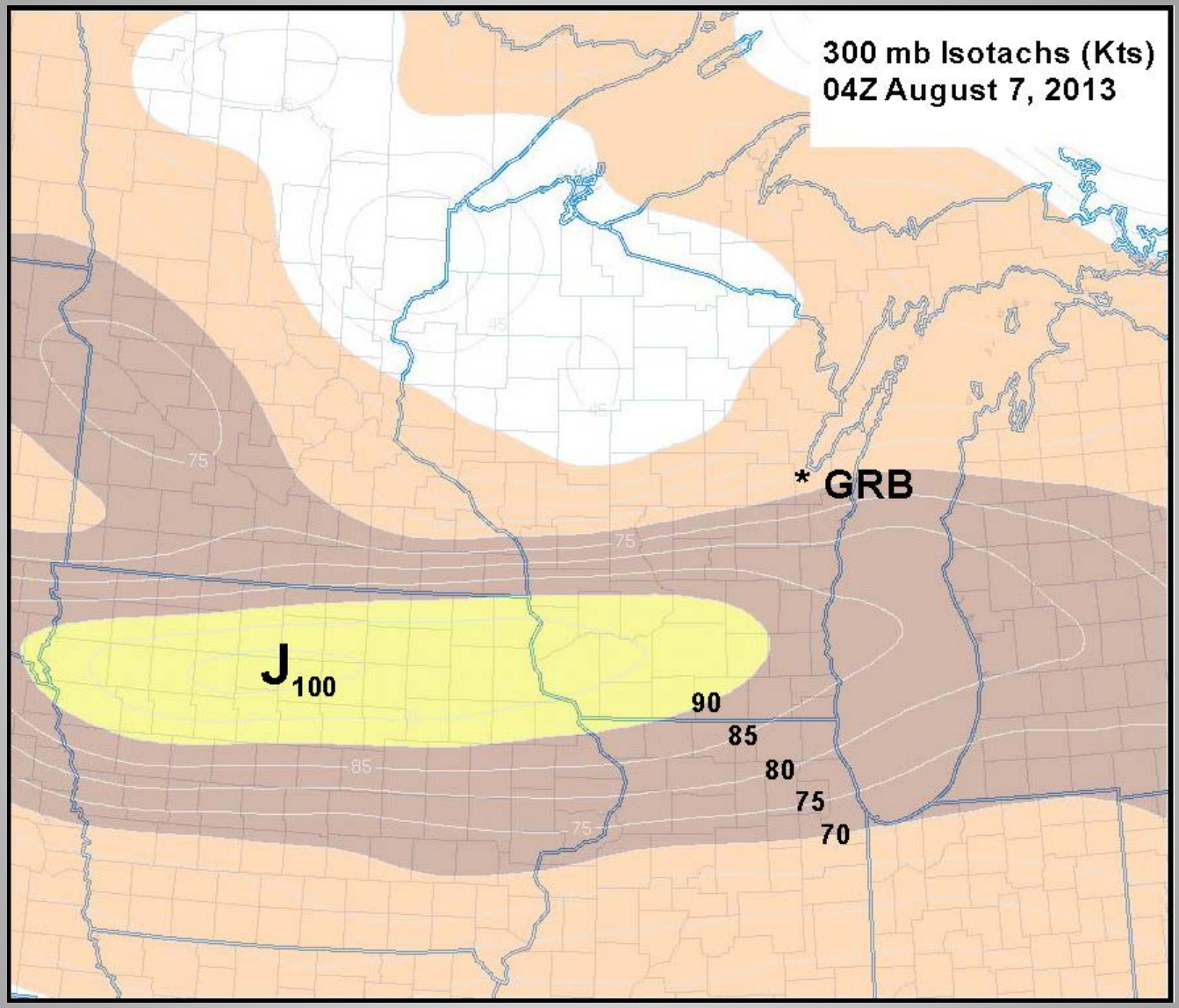
- ✓ Mesovortices form in association with a line surge/bow. Surge can be caused by RIJ, localized outflow, cell collapse.
- ✓ Surge creates localized updraft. Updraft tilts horizontal vorticity vertically and then gets stretched. Process (spin-up) is very fast.
- ✓ Most damaging mesovortices typically observed just north of bow apex/surge.
- ✓ Can have families or episodes of mesovortex development.
- ✓ Tornadic mesovortices can reach EF2/EF3 intensity.
- ✓ Given the low-level genesis, very rapid evolution and smaller scale, QLCS mesovortex tornadoes are more difficult to detect.

Synoptic & Mesoscale Setting

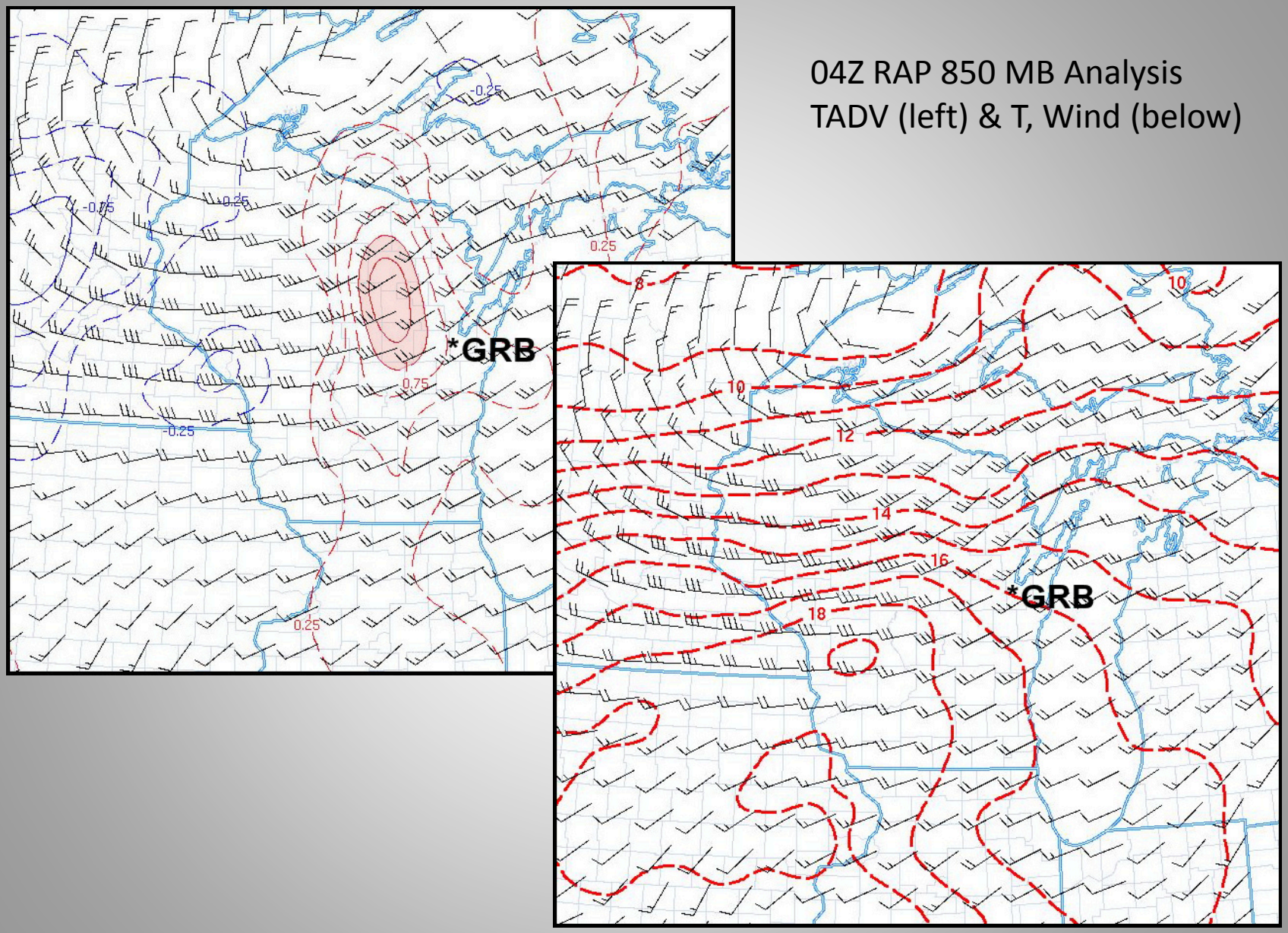
00Z – 05Z August 7, 2013

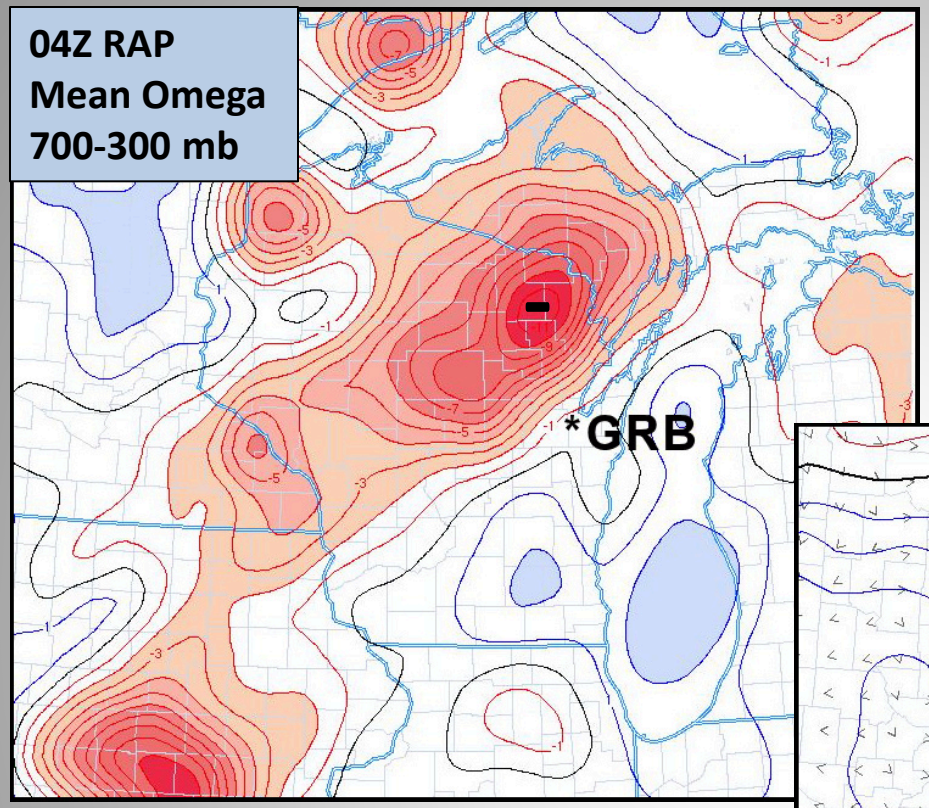

GRB
00Z August 7
500 MB Analysis


*GRB
00Z August 7
500 MB (H,V)

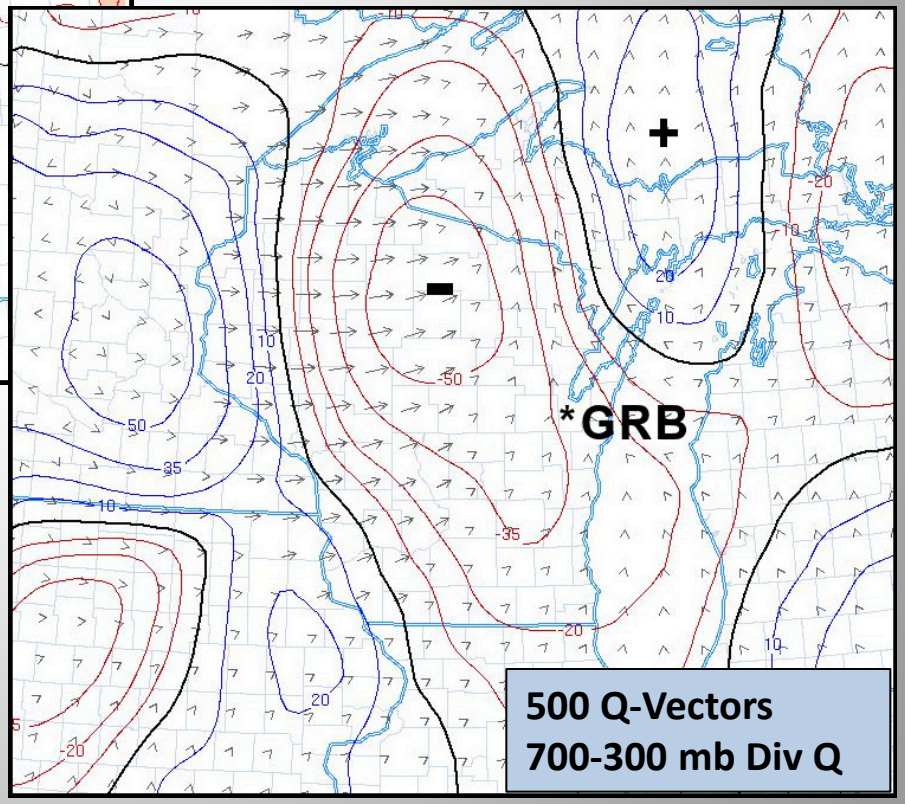

300 mb Isotachs (Kts)
04Z August 7, 2013
* GRB
J100
90
85
80
75
70

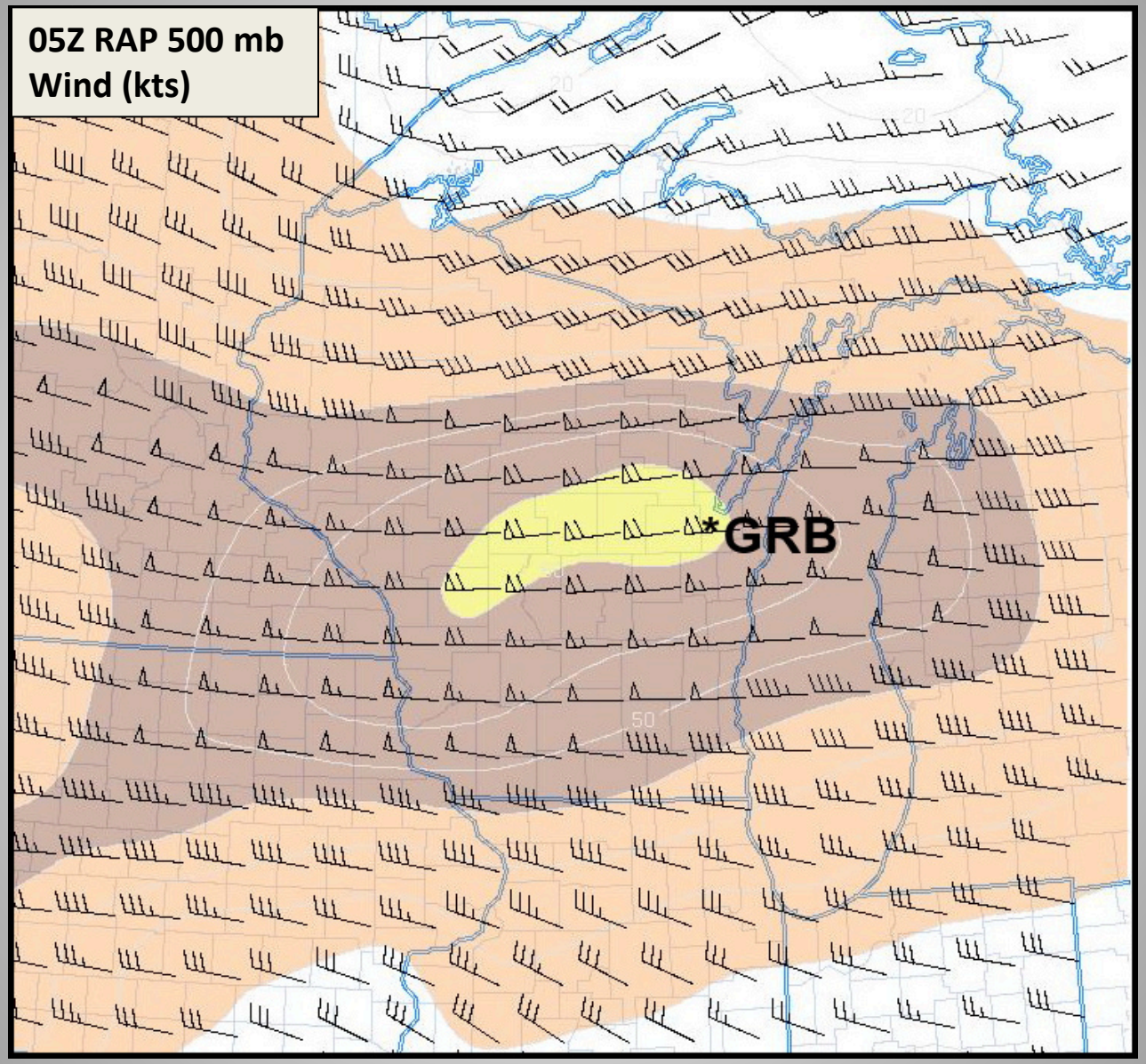
04Z RAP 850 MB Analysis
TADV (left) & T, Wind (below)

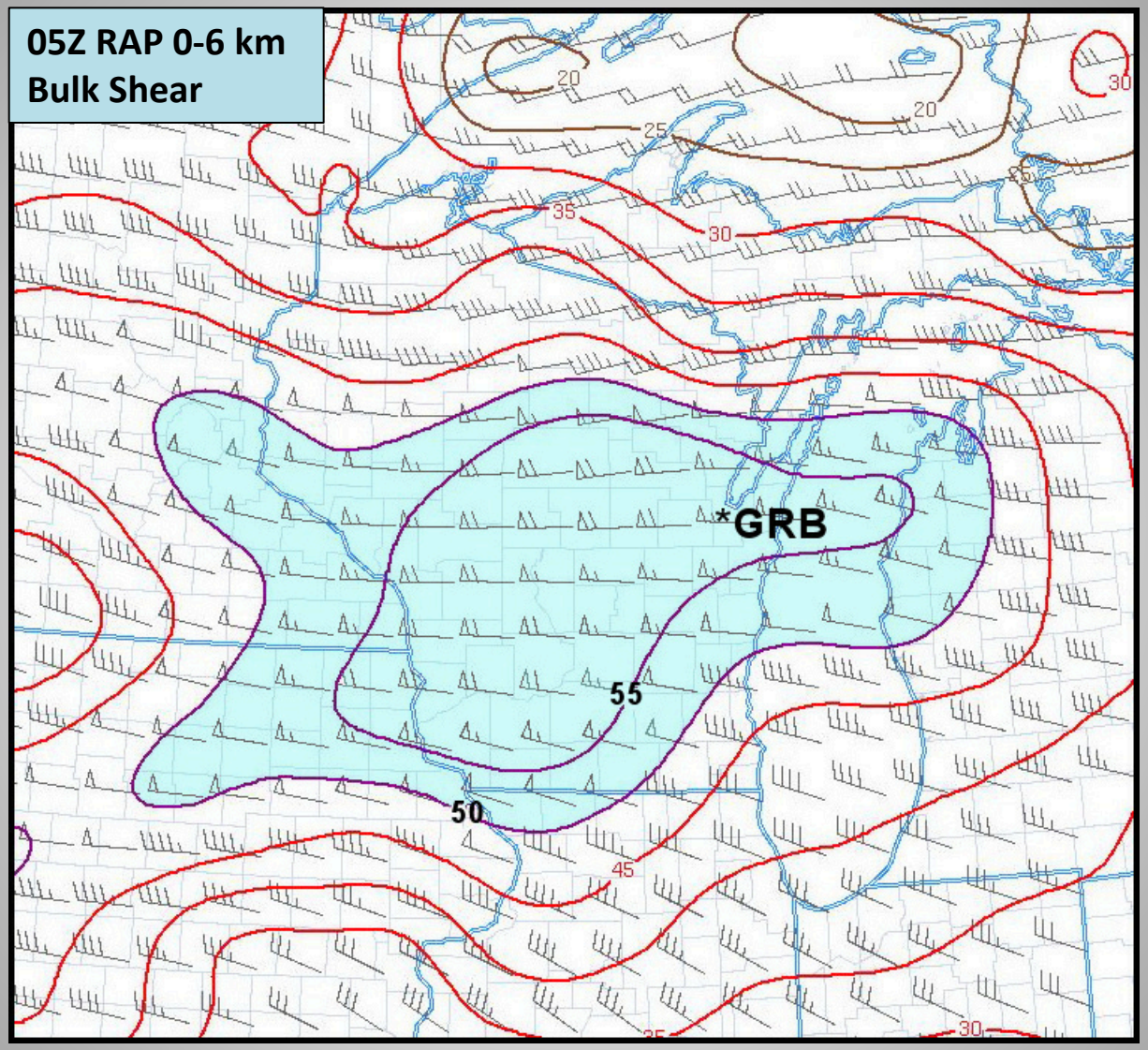


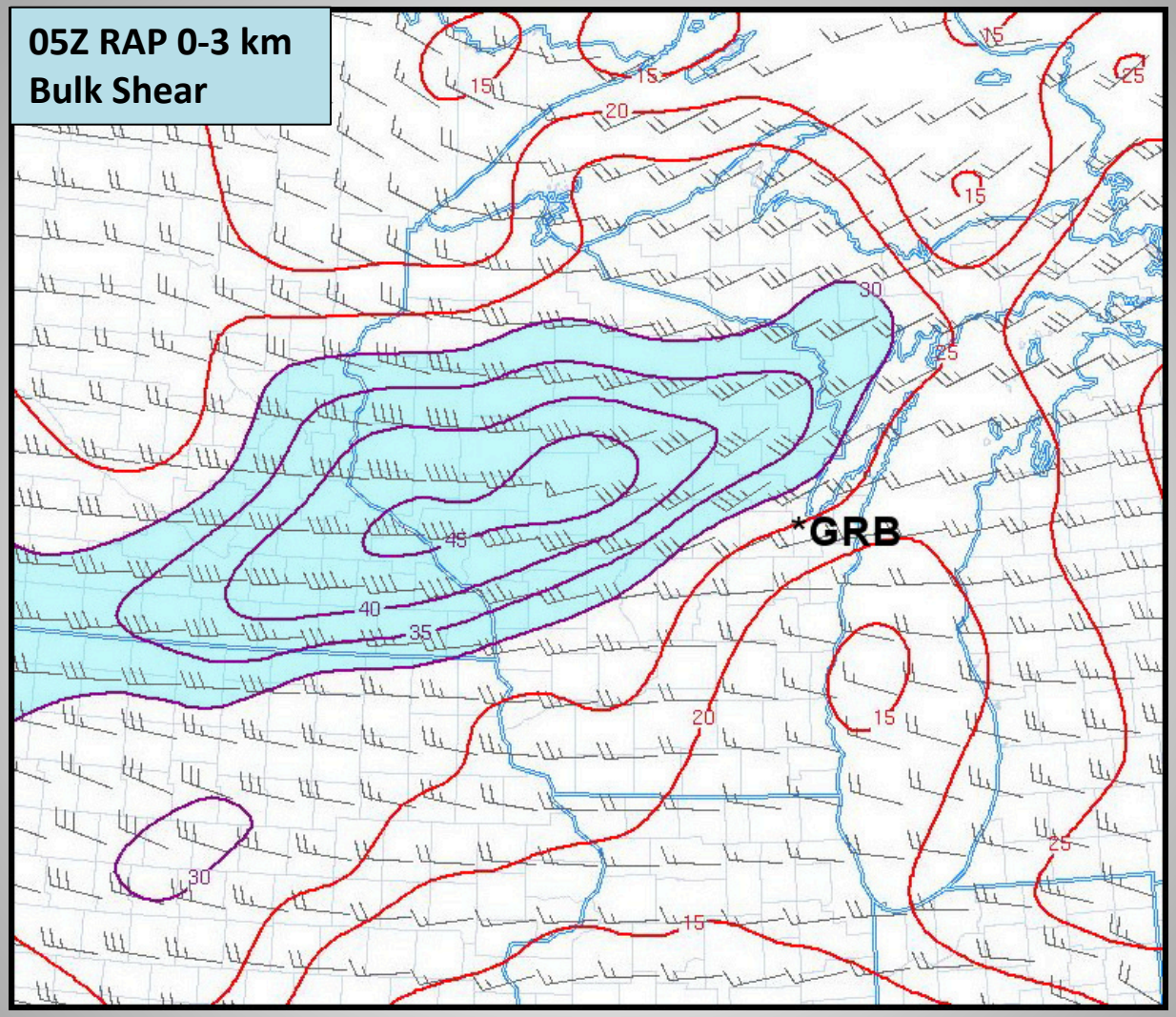


Robust vertical motion associated with forcing described earlier.

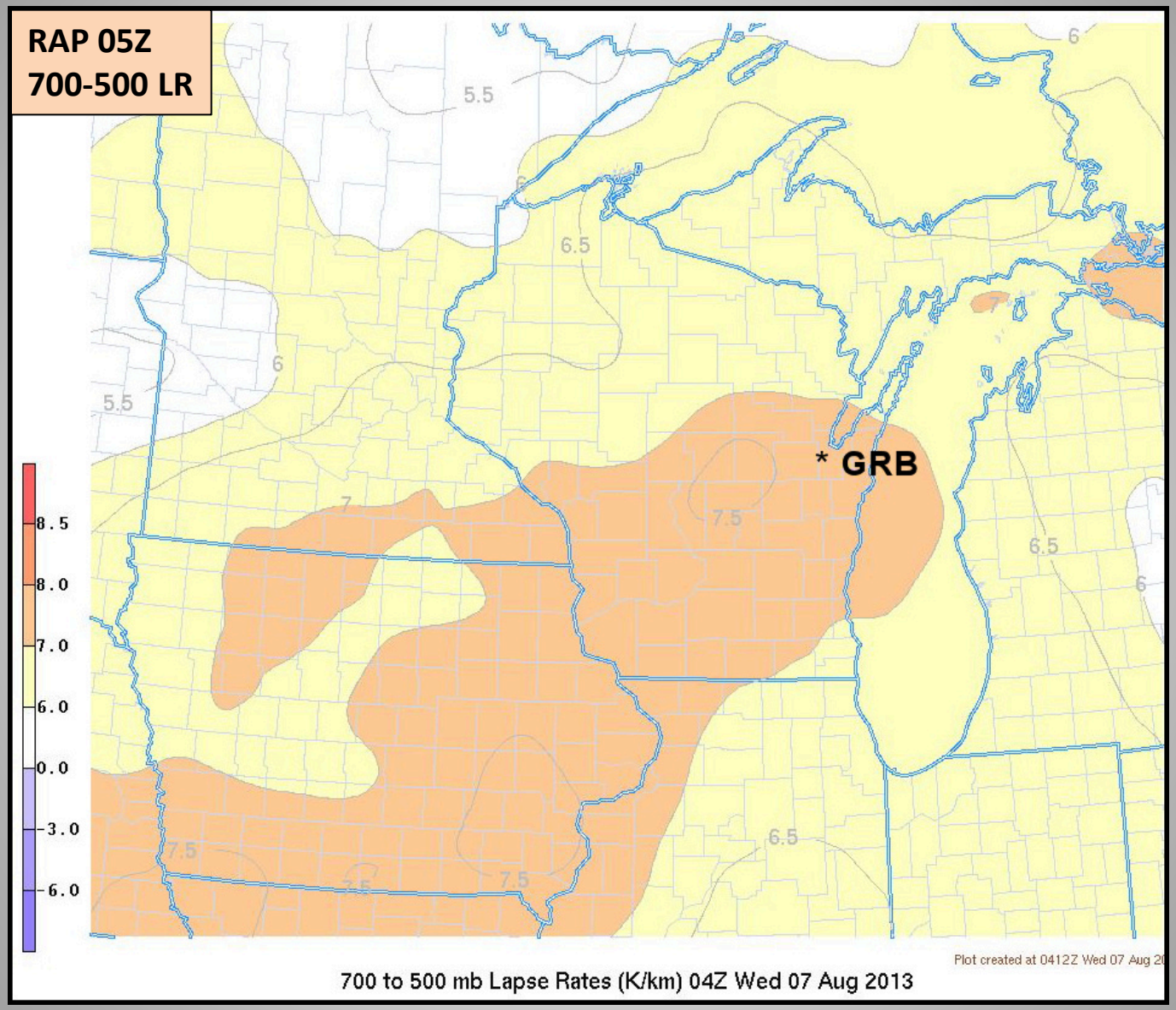


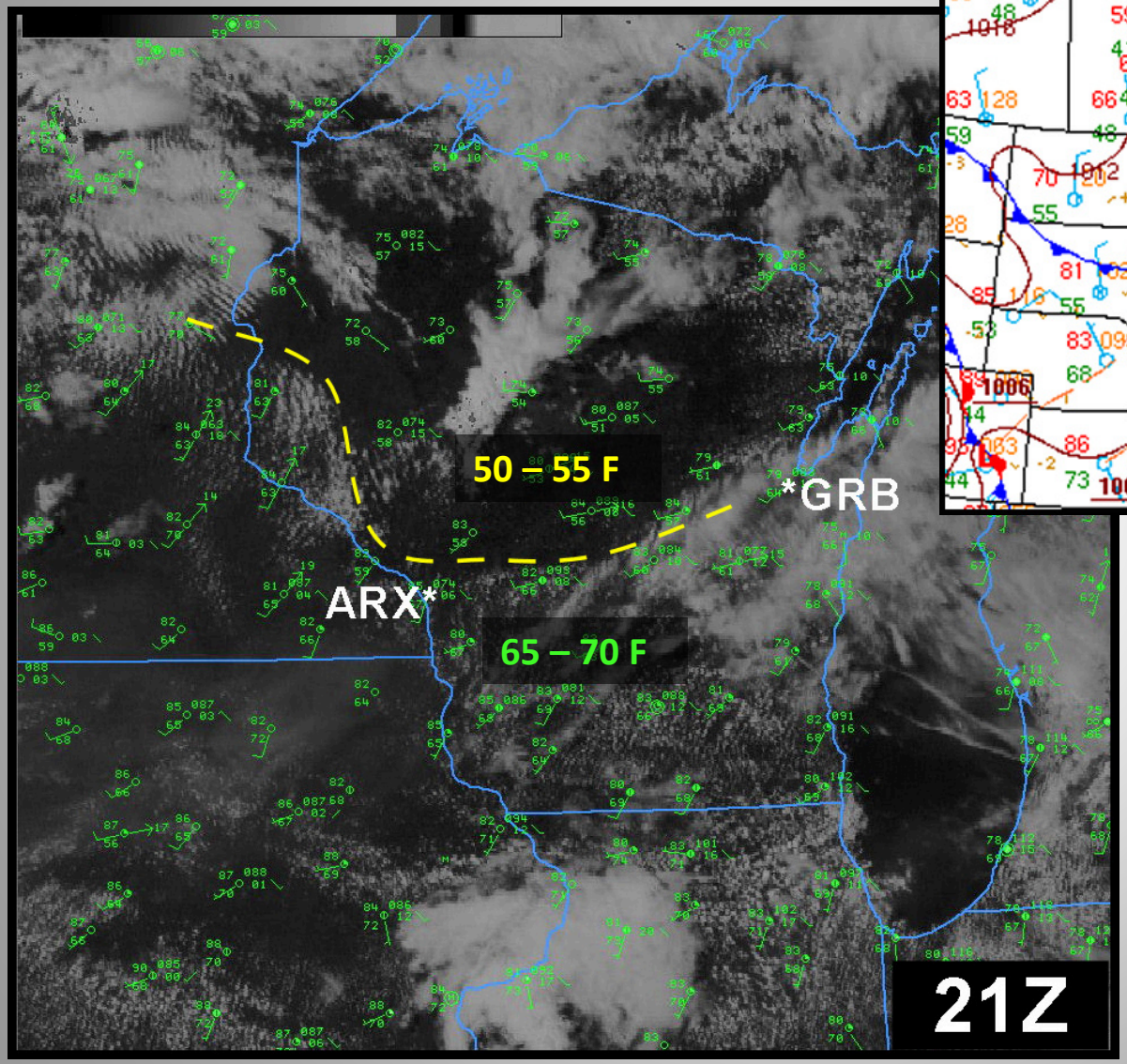

05Z RAP 500 mb
Wind (kts)
*GRB

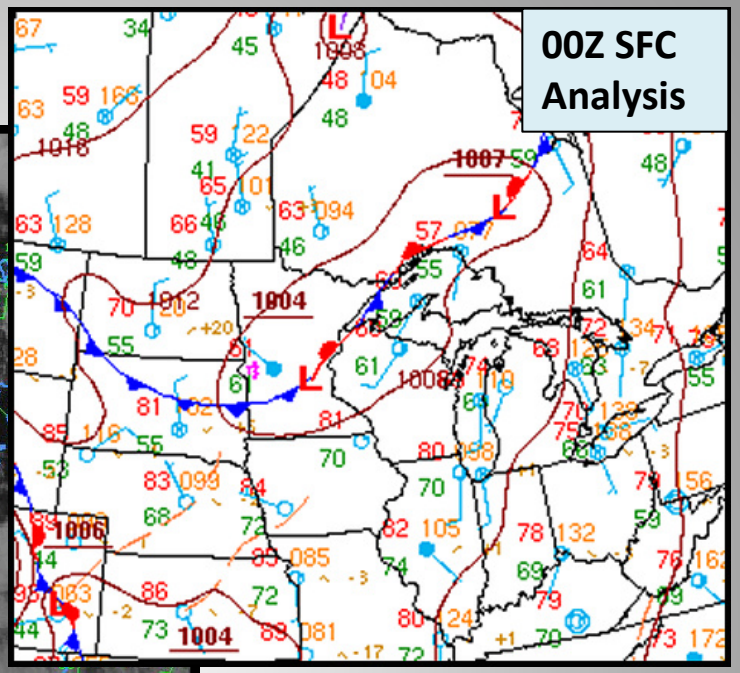

05Z RAP 0-6 km
Bulk Shear
20
25
20
30
35
30
*GRB
55
50
45
30



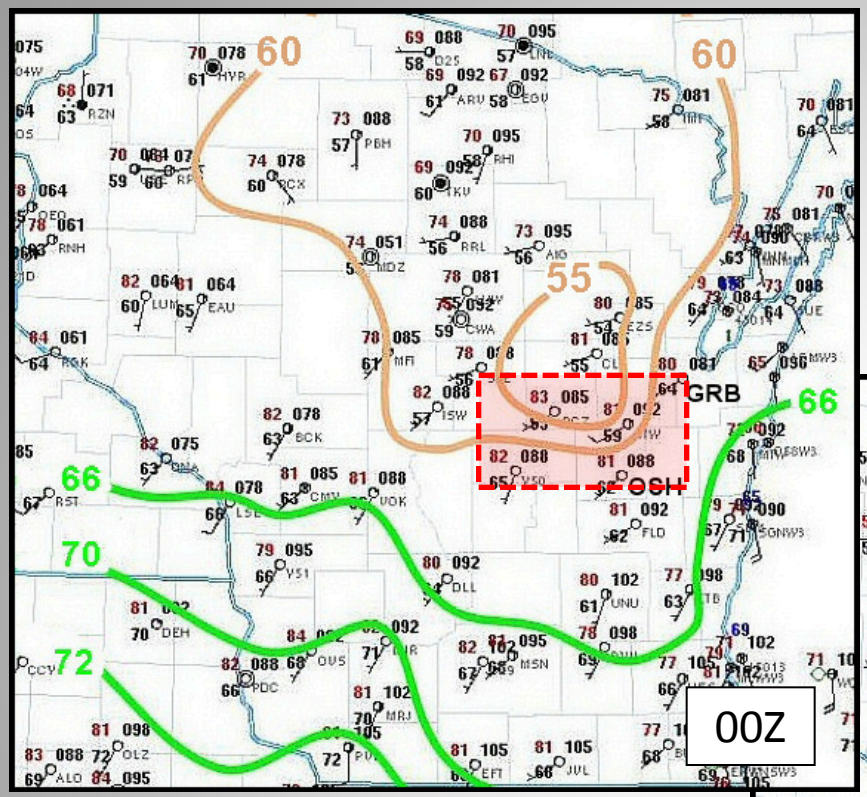
Line normal bulk shear $\geq$ 30 kts (15 ms^{-1}) favors QLCS mesovortex development (*Schaumann & Przybylinski 2012*)

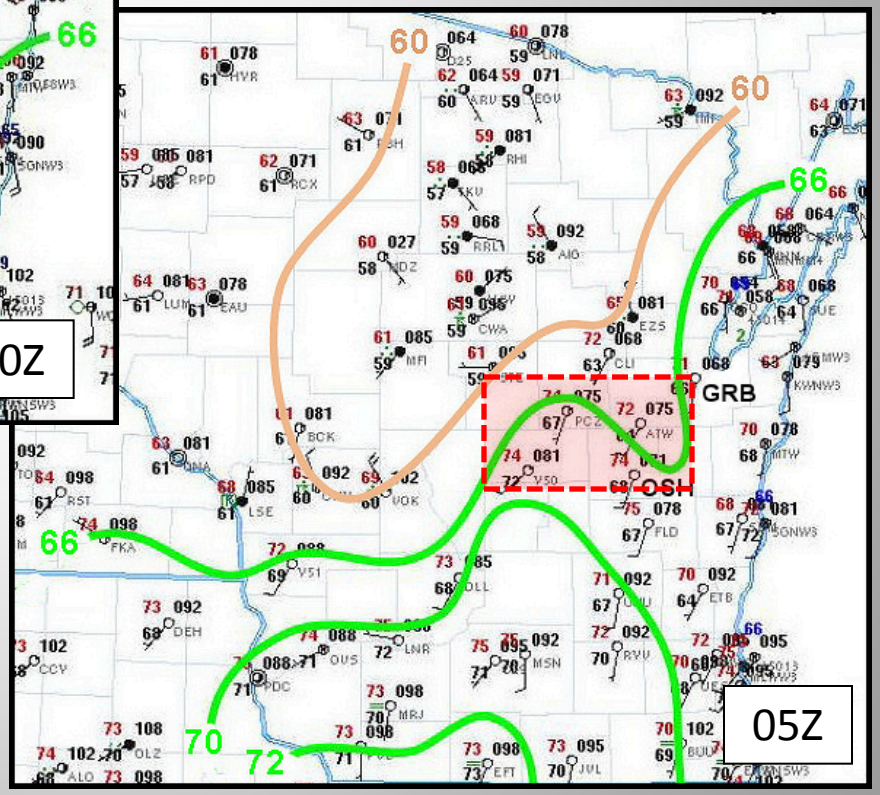

RAP 05Z
700-500 LR
* GRB
8.5
8.0
7.0
6.0
0.0
-3.0
-6.0
5.5
6
6.5
7
7.5
Plot created at 0412Z Wed 07 Aug 2
700 to 500 mb Lapse Rates (K/km) 04Z Wed 07 Aug 2013





Moisture discontinuity drifted northward during the evening.





Surface moisture increased over the Fox Valley during the evening

SB CAPE = 1378

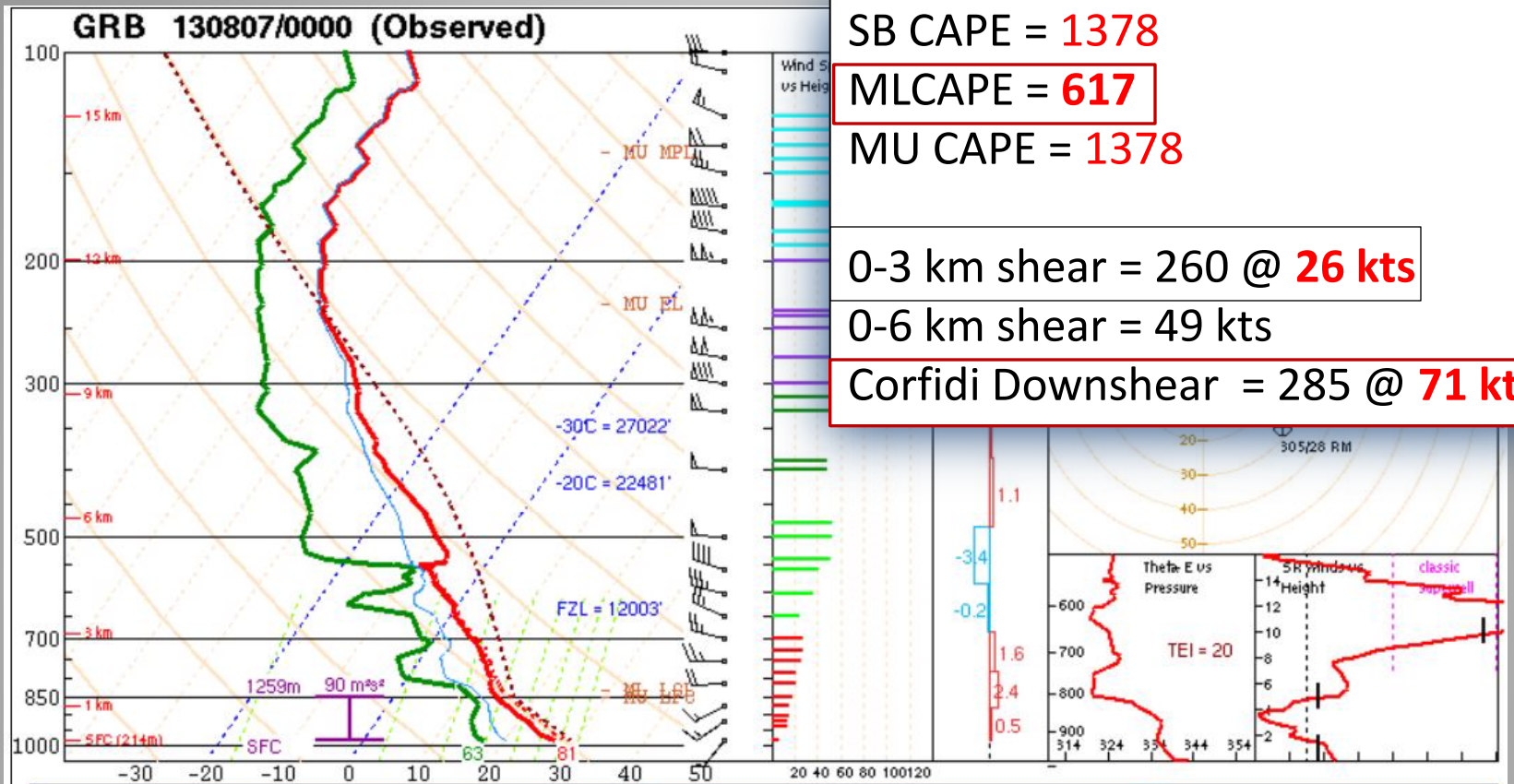
MLCAPE = **617**

MU CAPE = 1378

0-3 km shear = 260 @ **26 kts**

0-6 km shear = 49 kts

Corfidi Downshear = 285 @ **71 kts**



PARCEL	CAPE	CINH	LCL	LI	LFC	EL
SURFACE	1378	0	1259m	-4	1259m	36204'
MIXED LAYER	617	-3	1419m	-2	1481m	30390'
FCST SURFACE	959	0	1683m	-3	1683m	31960'
MU (984 mb)	1378	0	1259m	-4	1259m	36204'

PW = 1.20 .in	3CAPE = 32 J/kg	WBZ = 10329'	WNDG = 0.2
K = 29	DCAPE = 689 J/kg	FZL = 12003'	ESP = 0.8
MidRH = 56%	DownT = 60 F	ConvT = 81F	MMP = 0.90
LowRH = 65%	MeanW = 11.3 g/kg	MaxT = 84F	
SigSevere = 15705 m3/s3			

Sfc-3km Agl Lapse Rate =	8.2 C/km
3-6km Agl Lapse Rate =	5.9 C/km
850-500mb Lapse Rate =	6.1 C/km
700-500mb Lapse Rate =	5.9 C/km

Supercell = 2.5
Left Supercell = -0.0
Sig Tor (CIN) = 0.2
Sig Tor (fixed) = 0.4
Sig Hail = 0.6

	SRH(m2/s2)	Shear(kt)	MnWind	SRW
SFC - 1 km	75	11	236/13	152/27
SFC - 3 km	140	26	259/18	164/20
Eff Inflow Layer	90	13	237/13	153/26
SFC - 6 km		49	271/23	181/16
SFC - 8 km		53	272/26	191/15
Lower Half Storm Depth		50	271/22	177/16
Cloud Bearing Layer		91	278/39	235/19

BRN Shear = 36 m²/s²
4-6km SR Wind = 252/23 kt

.....Storm Motion Vectors.....
Bunkers Right = 305/28 kt
Bunkers Left = 246/31 kt

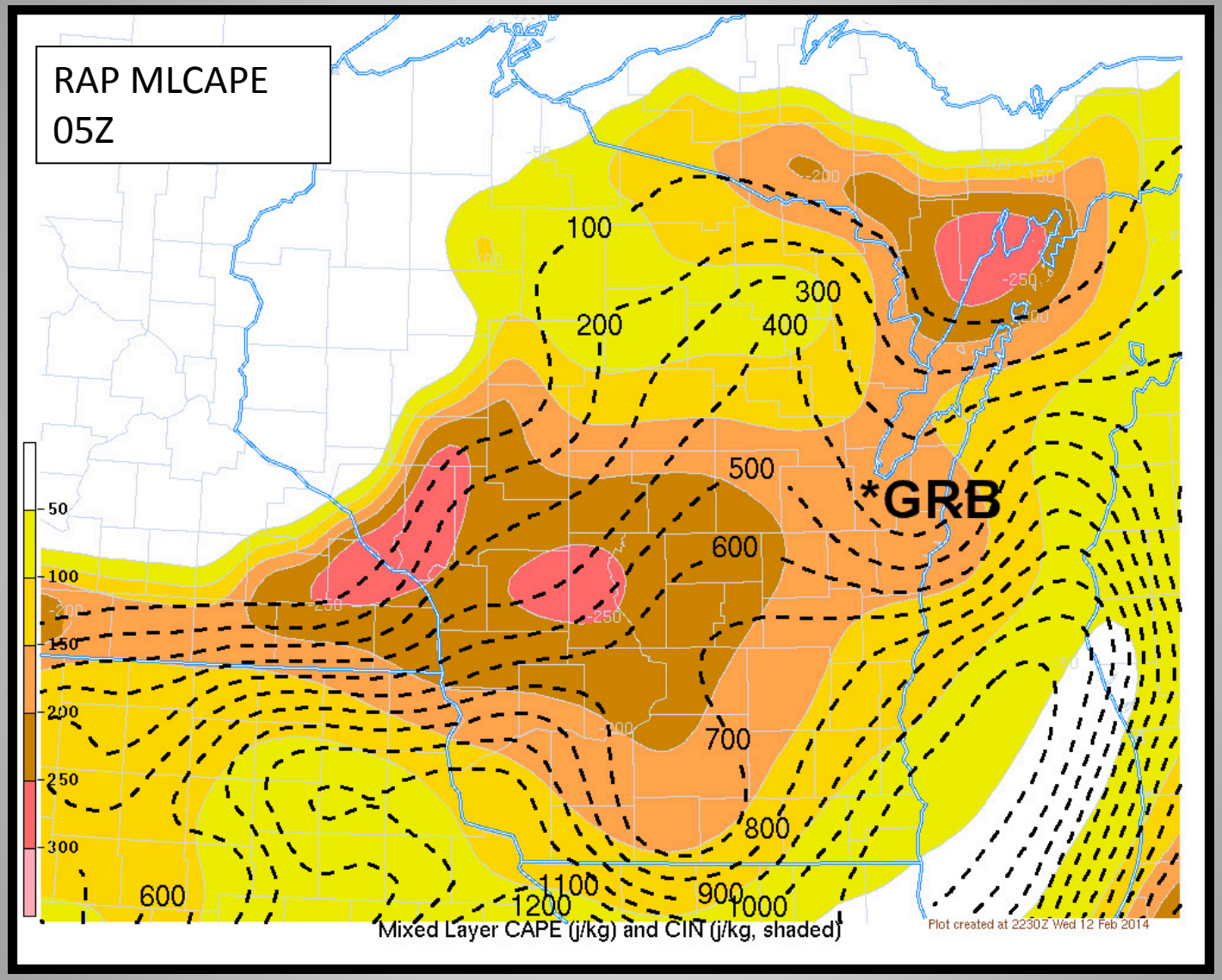
Corfidi Downshear = 285/71 kt
Corfidi Upshear = 295/31 kt

1km & 6km AGL Wind Barbs

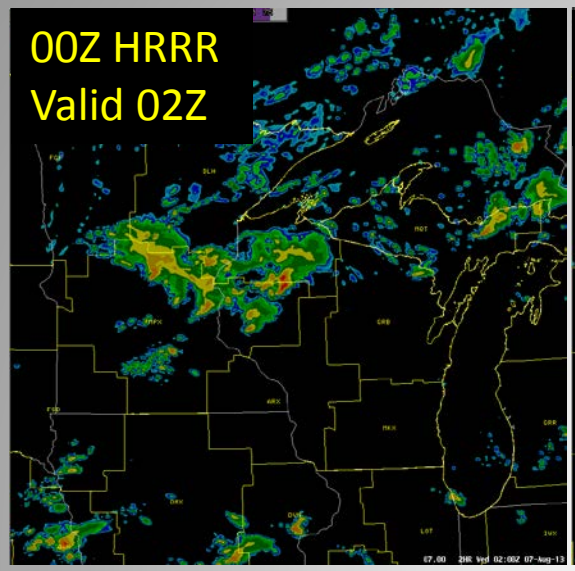
* * * BEST GUESS PRECIP TYPE * * *
None.
Based on sfc temperature of 81.3 F.

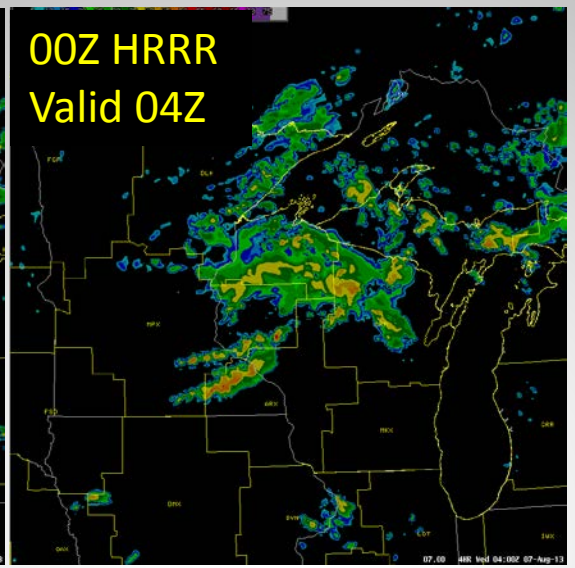
SARS - Sounding Analogs

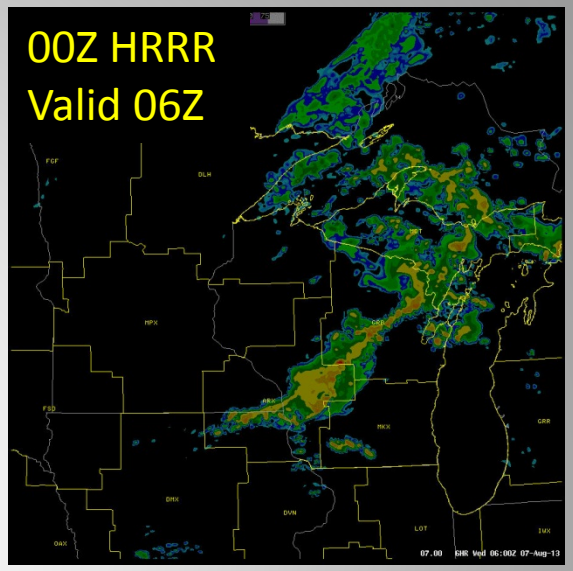
SUPERCELL	SGFNT HAIL
No Quality Matches	No Quality Matches
(6 loose matches) SARS: 33% TOR	(36 loose matches) SARS: 22% SIG


RAP MLCAPE
05Z
100
200
300
400
500
600
700
800
900
1000
1100
1200
600
*GRB
50
100
150
200
250
300
Mixed Layer CAPE (j/kg) and CIN (j/kg, shaded)
Plot created at 2230Z Wed 12 Feb 2014

Dramatic change in HRRR forecast convective structure between 00Z and 02Z







Synoptic/Mesoscale Summary

Environment became increasingly supportive for MCS organization into the late evening over the GRB forecast area

- Large-scale forcing organized and strengthened in concert with approaching shortwave trough, low-level WAA and LFQ of 90-100 knot 300 mb jet
- **Deep layer bulk shear** (0-6 km) ~ 55- 60 KTS. **0-3 km shear** ~ 260 @ 25-30 KTS based on 00Z GRB RAOB and RAP. 0-3 KM shear (RAP) increased during evening
- Approximate E-W surface boundary/moisture gradient situated over central and east-central Wisconsin. Drifted northward during the evening.
- Low-level moisture increased over east-central Wisconsin during the evening perhaps slowing stabilizing effect of nocturnal cooling.
- Overall instability (MLCAPE) ~ 500-600 J/kg. MLCIN ~ -100 to -150 J/Kg.
- Generally **moderate-high shear / low instability environment**.

Classification of Quasi Linear Convective Systems (QLCS) (Including embedded Bow Echoes within QLCSs) and Mesovortex Characteristics across WFO St. Louis County Warning Area (CWA) and surrounding CWAs

Ron W. Przybylinski (SOO) WFO St. Louis
Jim Sieveking (Lead Forecaster) WFO St. Louis
Gary Schmocker (Forecaster) WFO St. Louis

Note: Only small sample of Type 1 cases shown. To be updated.

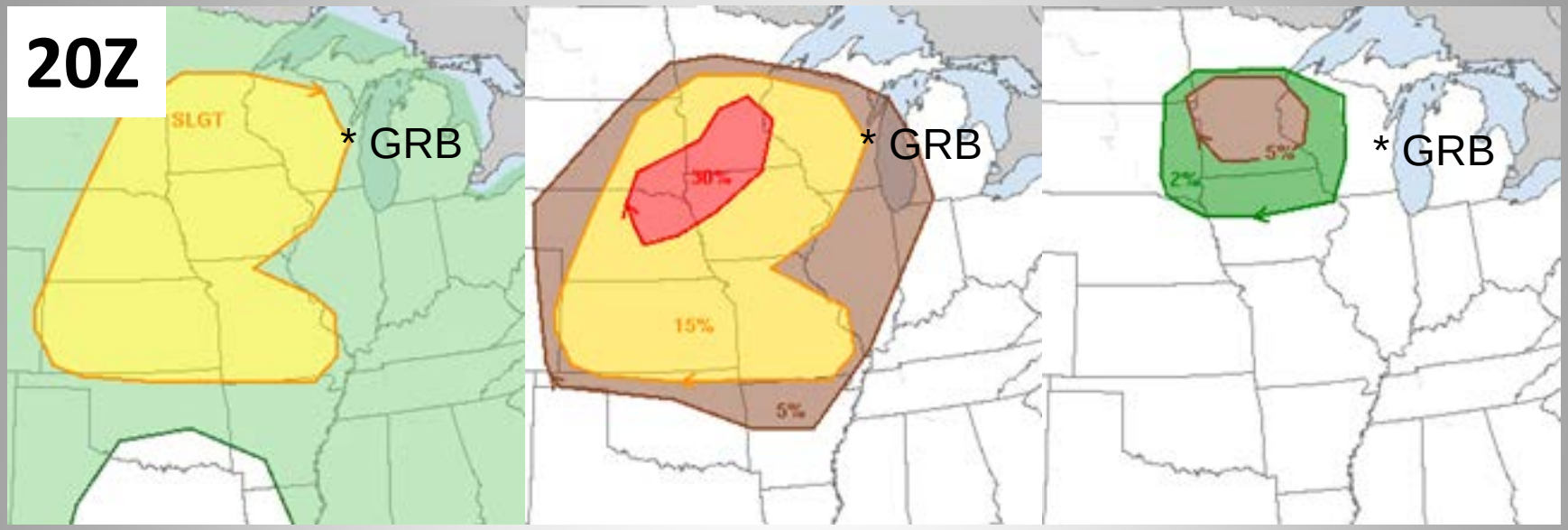
http://www.crh.noaa.gov/lsx/?n=qlcslatest

Group 1	Surface boundary intersecting the *northern end* of a convective line.

Non-Tornadic

Case #	1	2	3	4	5	6	7/BE1	8	9	10	Aug 7	Tulsa
Derecho	Y	Y	Y	Y		Y			Y		N	N
Shear 0-5 km	19 m/s	11	17	13	19	15	11	19	20	21	28	28
Shear 0-3 km	18 m/s	09	13	06	13	14	07	15	17	17	14	21
ML CAPE	4500 J/Kg	3600	3500	3750	4500	3400	4300	3300	2675	3400	500	1000

Expectations



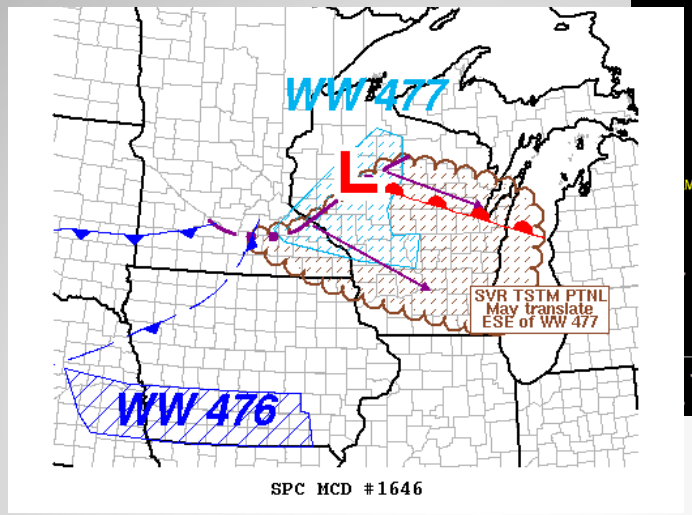
…Initially, a few supercells, possibly tornadic in warm sector over southern Minnesota…otherwise the evolution of one or more organized mesoscale convective systems appears possible…accompanied by the risk for severe winds and hail before diminishing overnight…

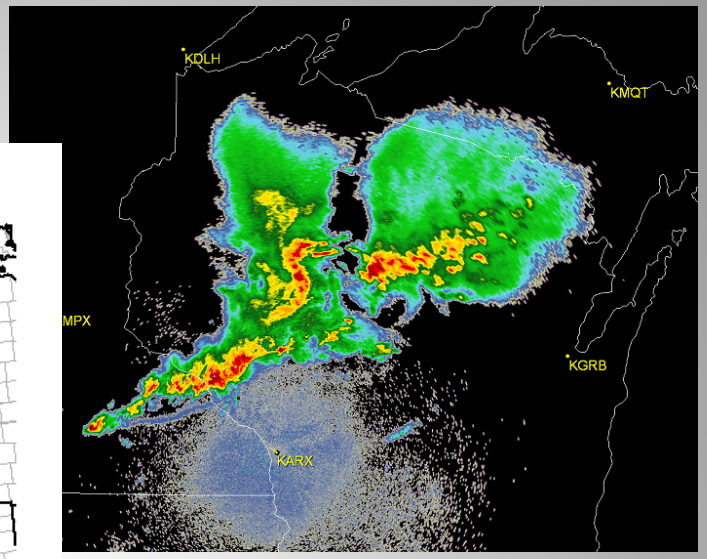
Expectations

…Ongoing semi-discrete/supercellular storms are likely to persist east-southeastward while gradually merging into line segments into WI/eventually MI the remainder of the night. Bouts of severe hail/damaging winds will remain possible.

Expectations

1015 PM CDT
SPC MCD





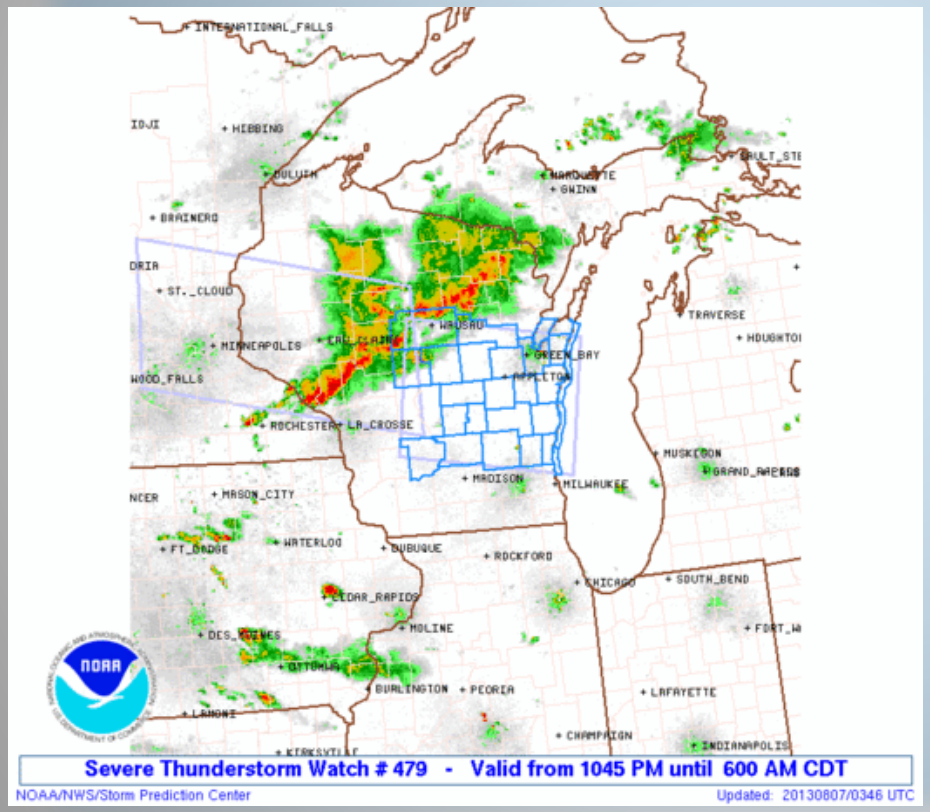
Outflow from several areas of convection is **aggregating into single cold pool**…with increasing thunderstorm coverage overall…

…although sfc diabatic cooling is expected to strengthen MLCINH ahead of this activity…near-sfc moist advection will make that process gradual.

…"forced ascent" associated with forward propagating MCS cold pool…and enhanced amidst downward momentum transport from belt of 50kt mid-level flow…may be sufficient to "offset shallow layer of relatively stable air" and spread damaging wind threat eastward…

Expectations

1045 PM CDT

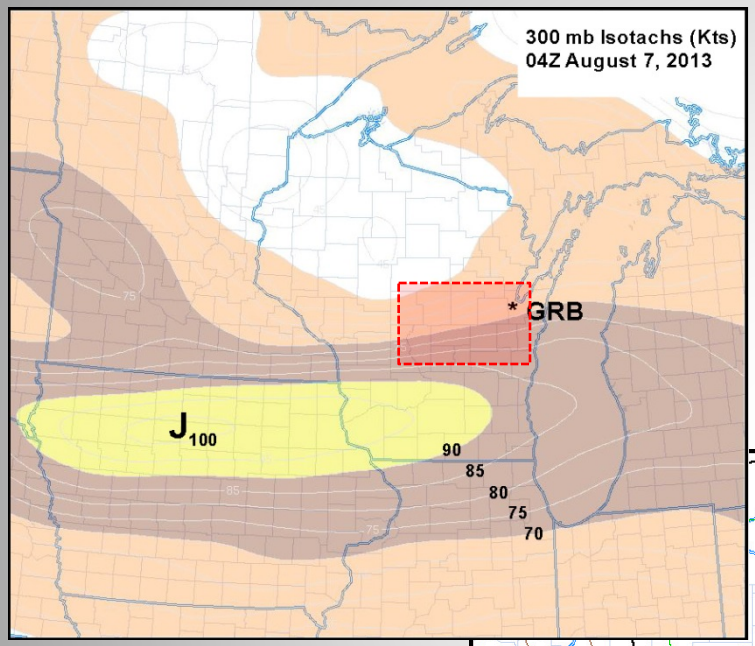


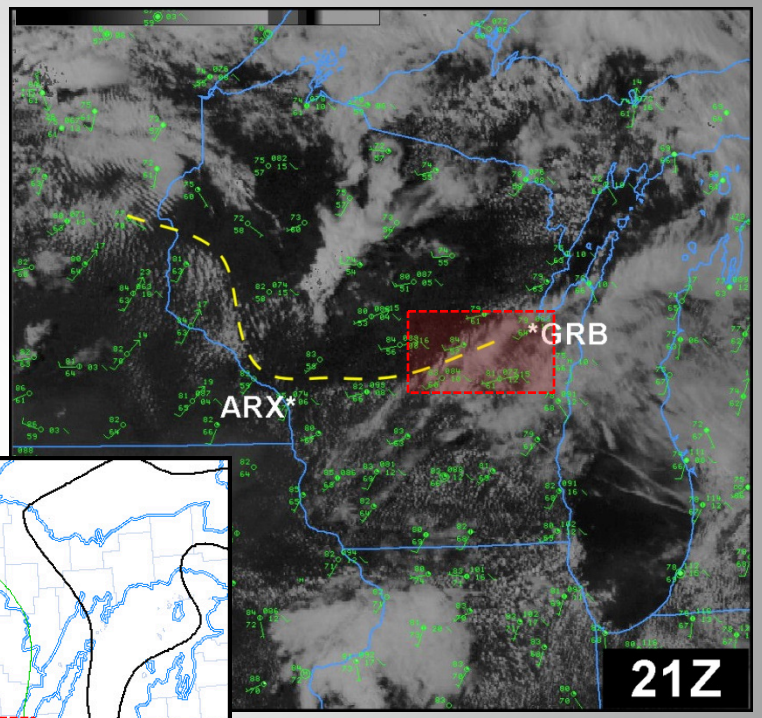
- Intermittent damaging wind threat expected
- No discussion of possibility of tornadoes
- Although not explicitly mentioned, SPC discussions of cold pool organization during the evening would suggest consideration of forecast 0-3km shear immediately downstream of organizing cold pool

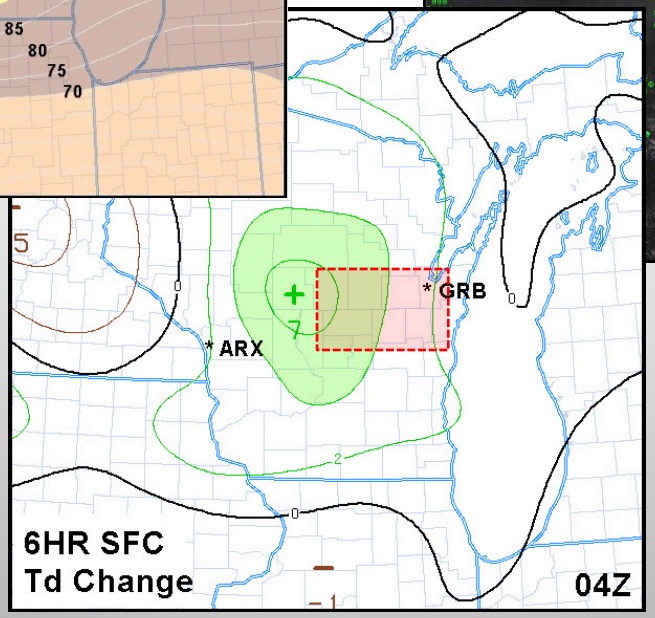
Expectations - Summary

- Minor change in expectations from **20Z** and subsequent **01Z** SPC Outlook.
- Although not explicitly mentioned, 2% tornado threat nudged eastward to include the western portion of east-central Wisconsin / Fox Valley.
- Some uncertainty persisted as to degree of severe wind threat downstream given continued nocturnal cooling.
- Overall thinking was initial discrete surface-based convection west of the Mississippi River Valley could potentially grow upscale into more organized convective systems and move across the GRB forecast area overnight.
- Primary threat large hail and intermittent damaging winds.

Setting The Table - SA Challenges



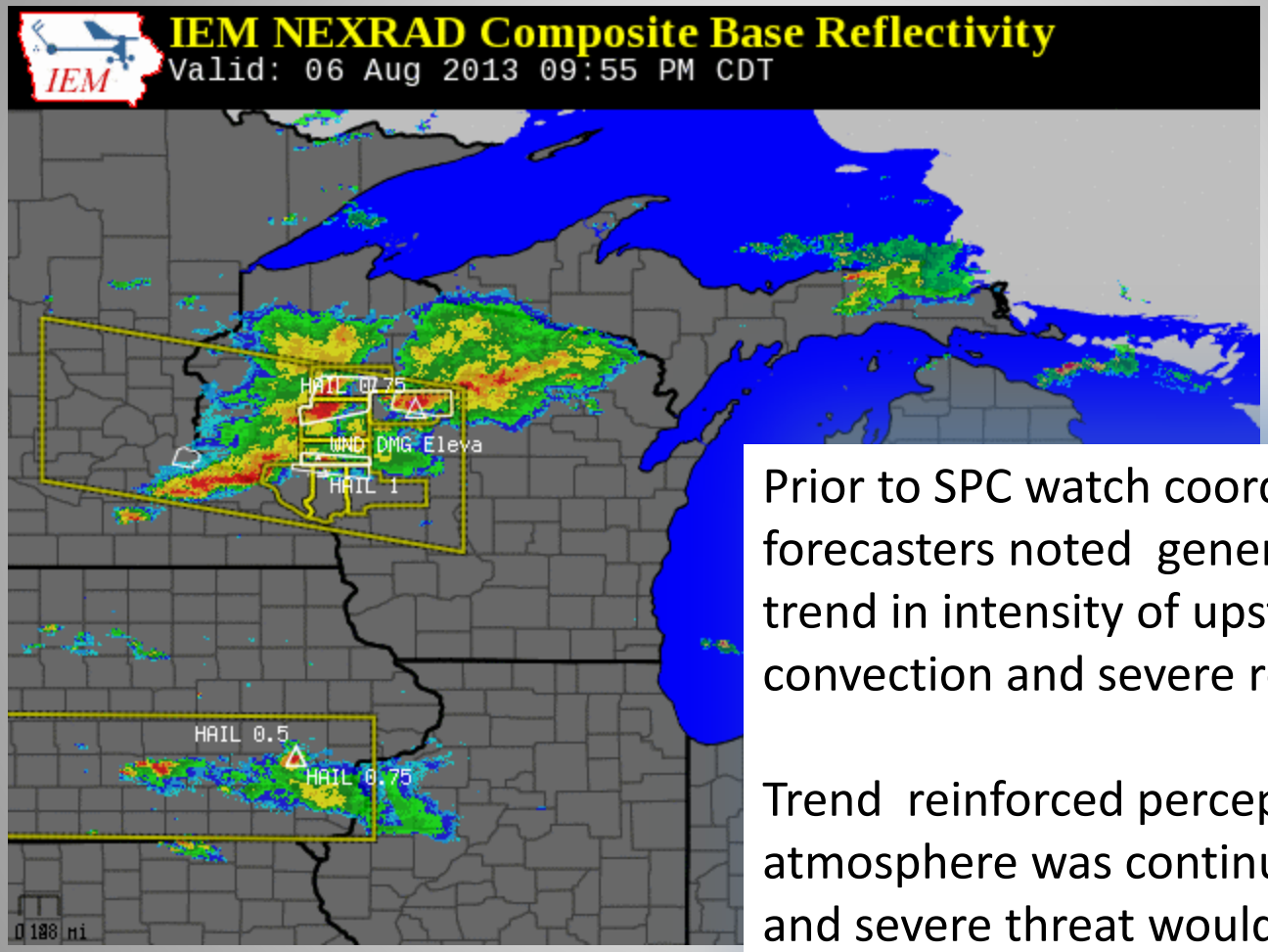




Synoptic forcing stronger and more organized than originally expected
(recall HRRR forecast)

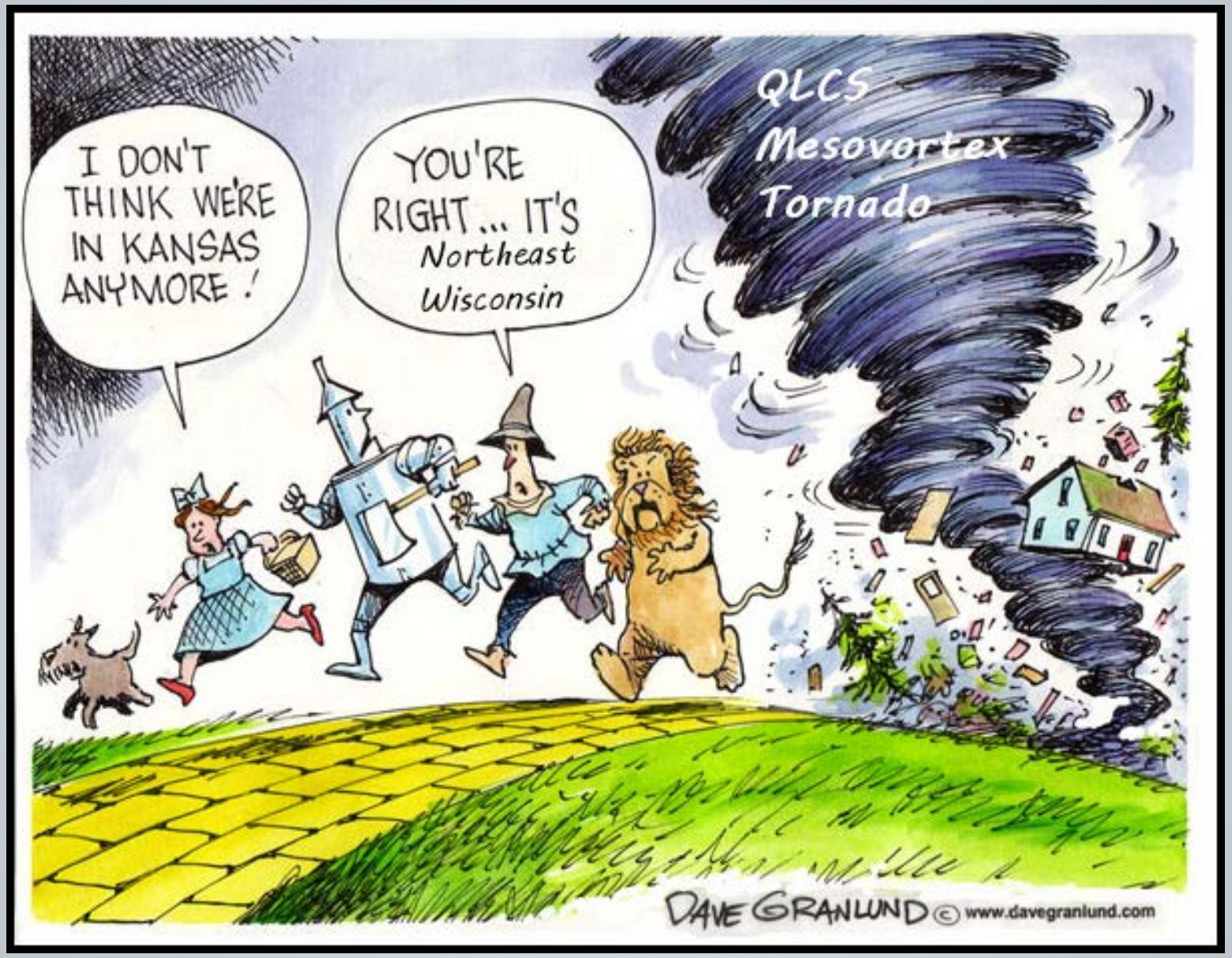
MCS organization was occurring within an <u>increasingly</u> supportive synoptic-scale setting.

Situational Awareness

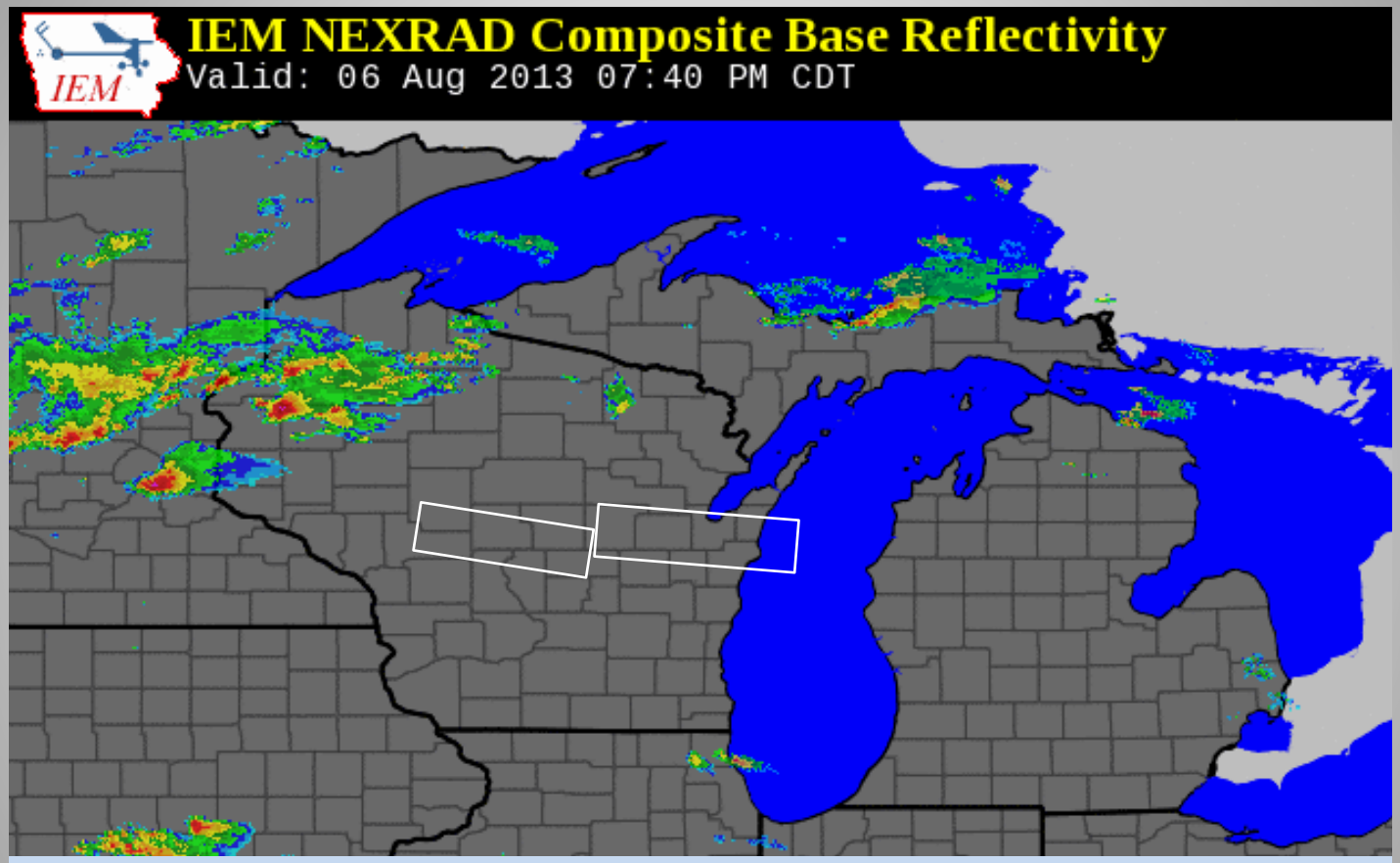


Prior to SPC watch coordination, forecasters noted general downward trend in intensity of upstream convection and severe reports.

Trend reinforced perception that atmosphere was continuing to stabilize and severe threat would likely be minimal.

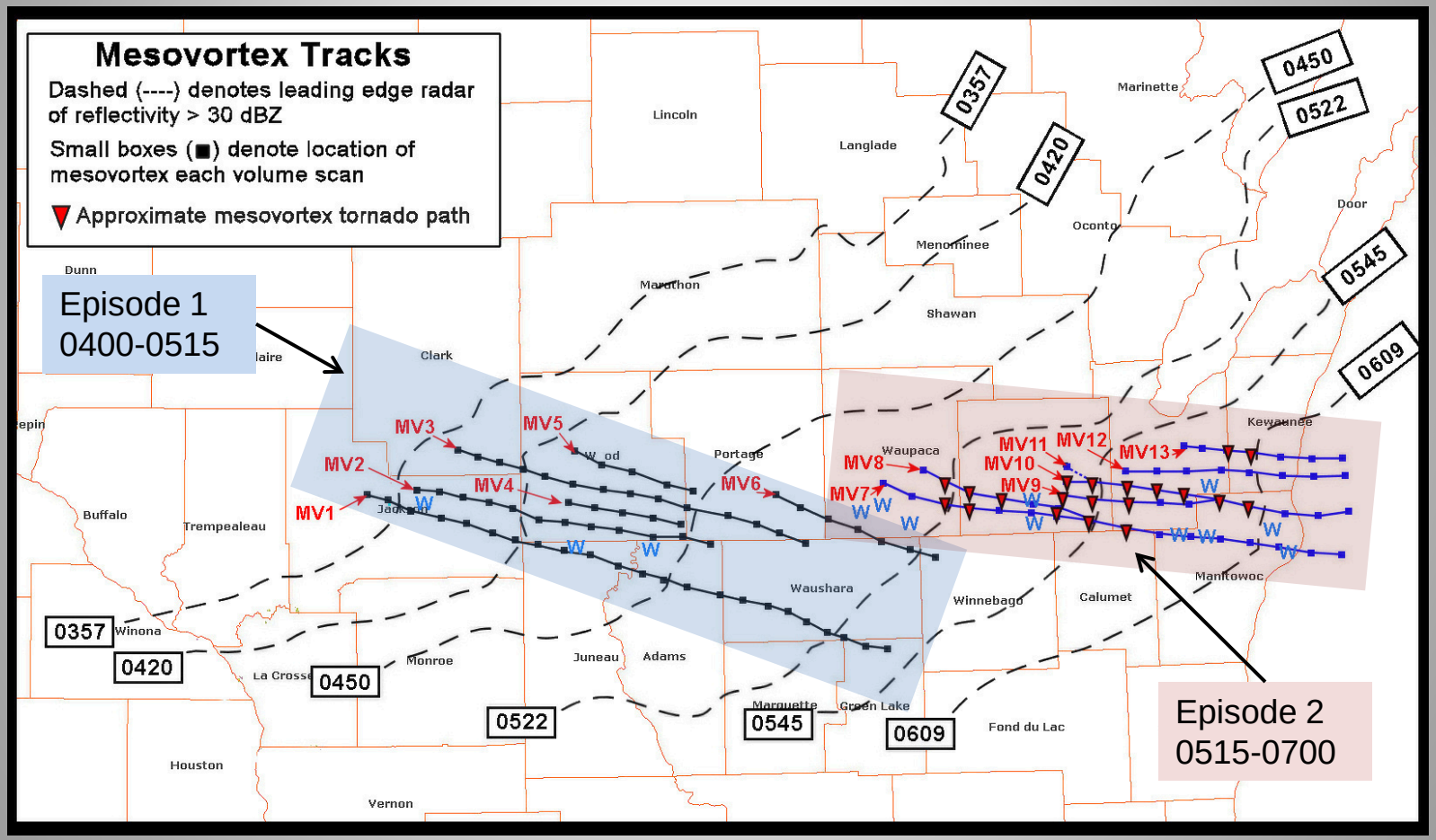

I DON'T THINK WE'RE IN KANSAS ANYMORE!
YOU'RE RIGHT... IT'S Northeast Wisconsin
QLCS Mesovortex Tornado
DAVE GRANLUND © www.davegranlund.com

Radar Evolution

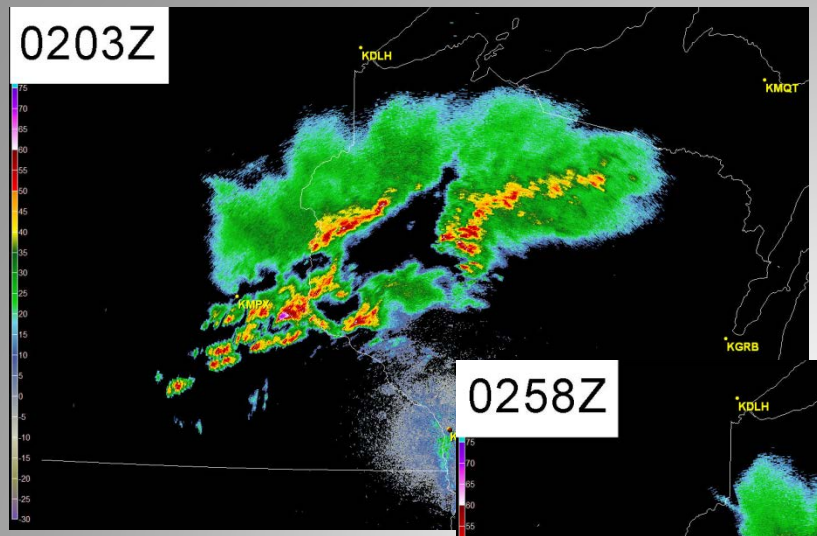


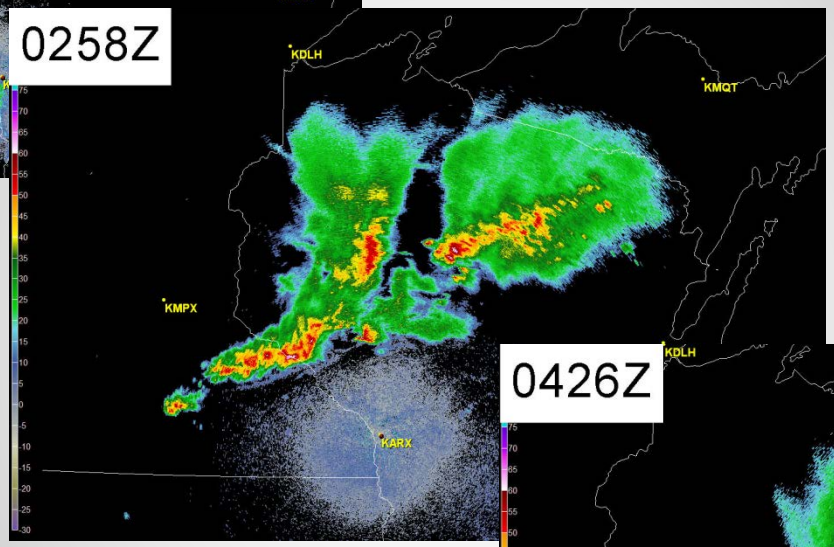
Two episodes of mesovortex development were observed. In both cases, mesovortex genesis occurred in concert with a surge/pivot of a line segment embedded within the QLCS.

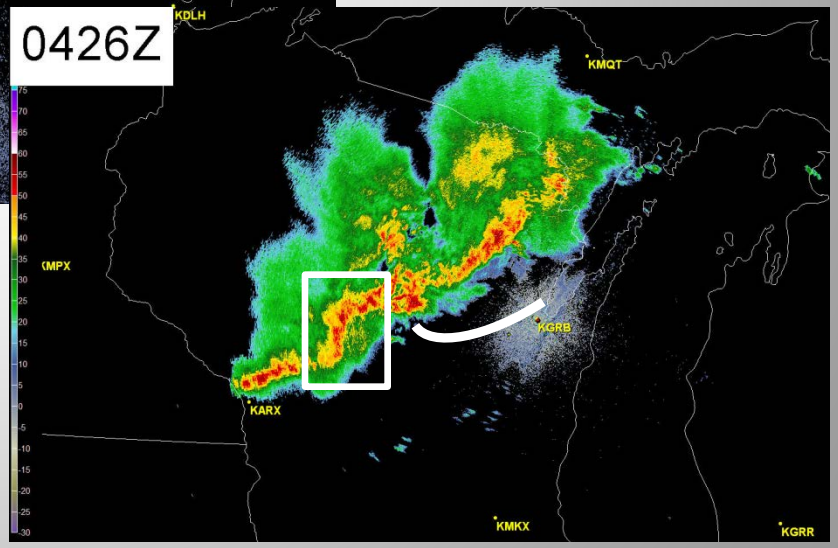
Preliminary QLCS Mesovortex Tracks



Mesovortex Episode 1
02Z – 05Z





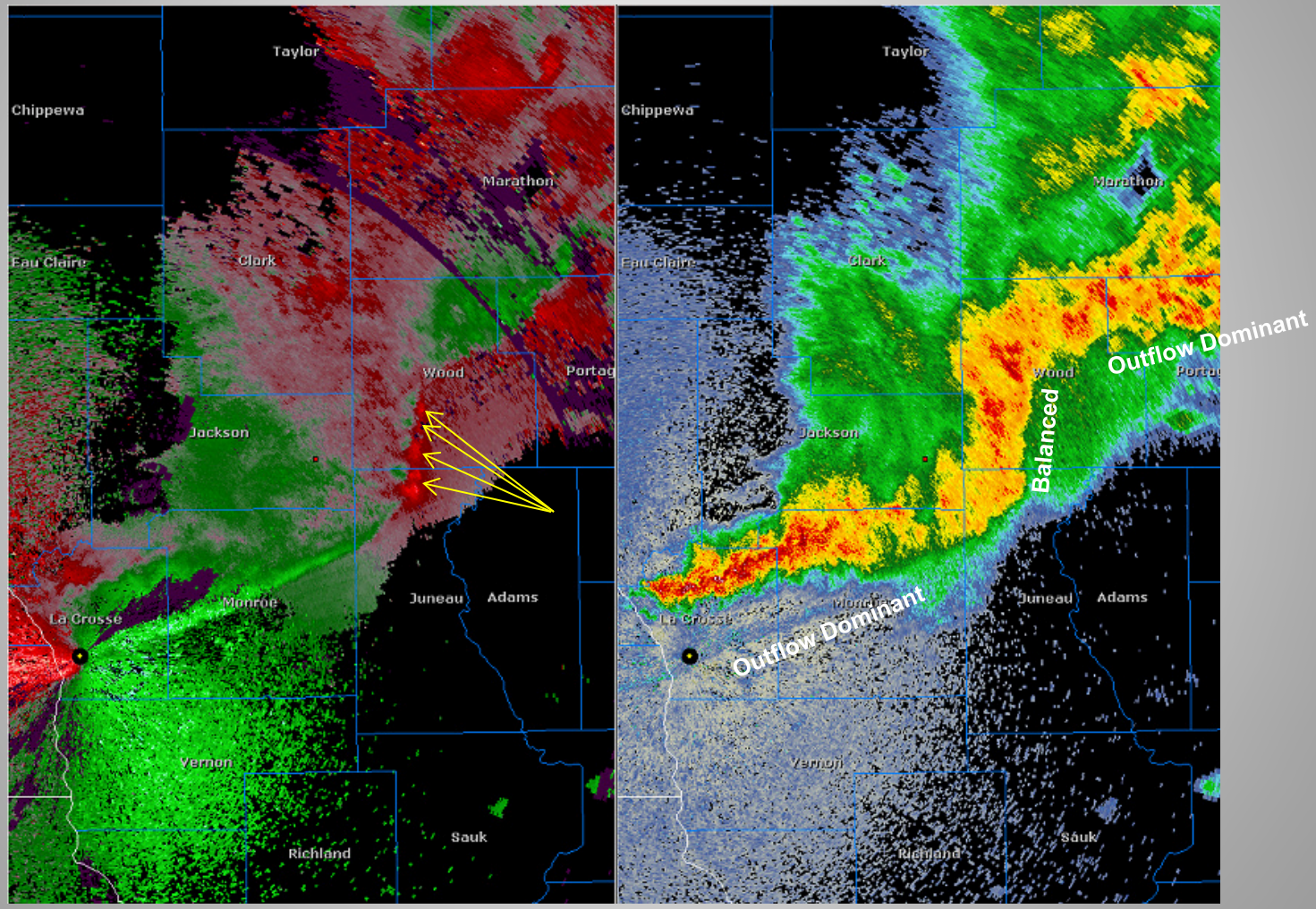


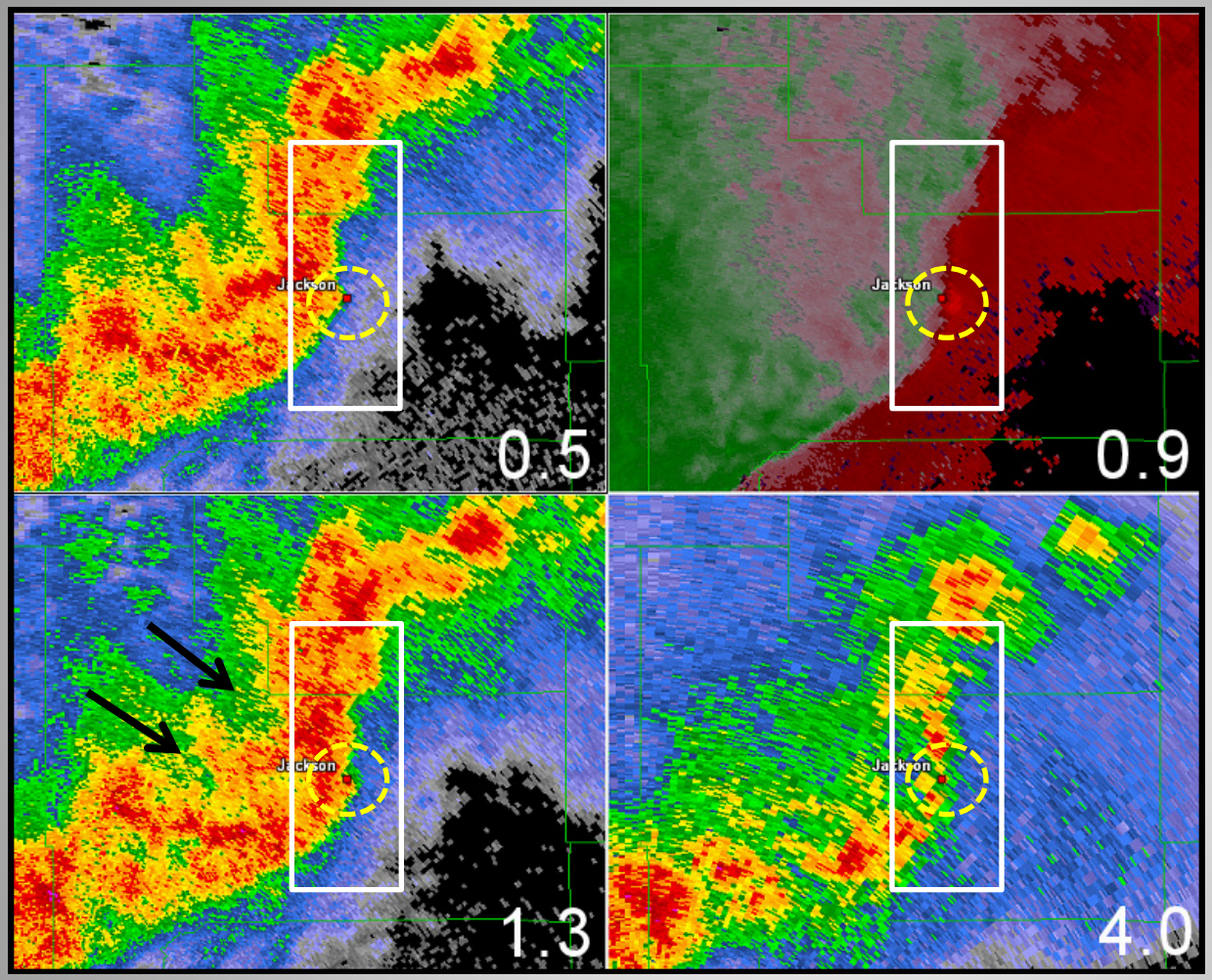
- MCS Congeals & Cold Pool Organizes
- RIJ develops
- Southern Portion of QLCS surges/pivots east of ARX

- Weak mesovortices develop as line pivots N-S
- Outflow dominant portion of the QLCS <u>further downstream</u> generates E-W outflow ahead of developing bow

Radar Evolution

0345Z - 0430Z



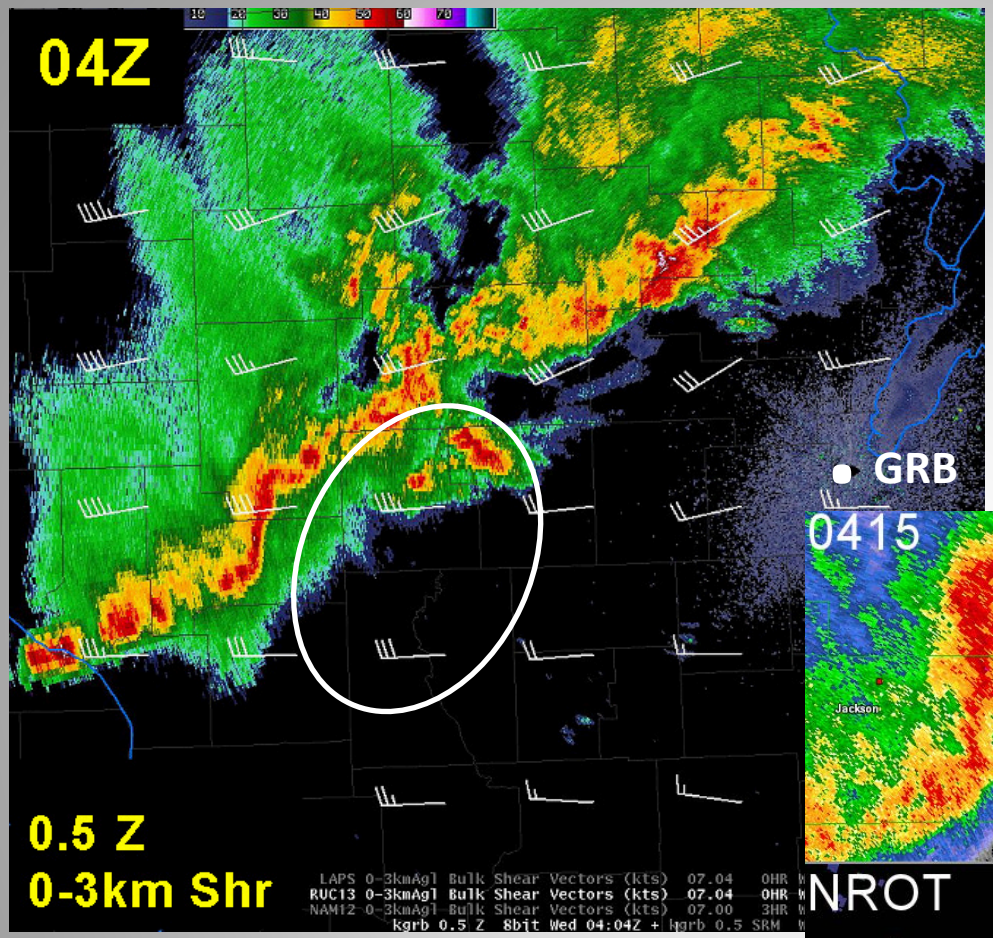


Radar Indications of Balance

- ✓ UDCZ on leading edge
- ✓ Tight reflectivity gradient
- ✓ Upright updrafts
- ✓ Trailing stratiform

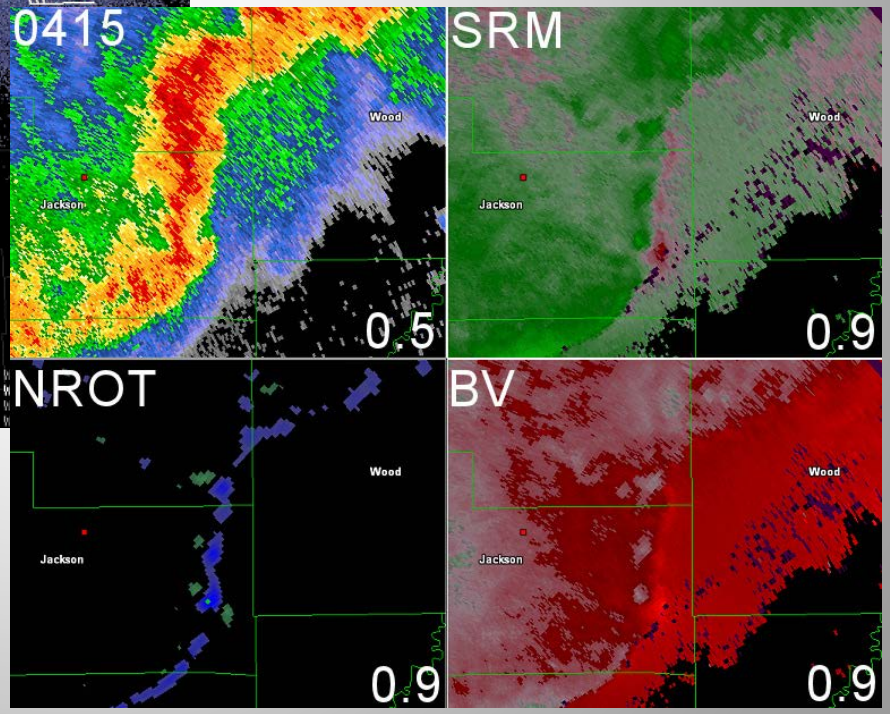
Also note RINs at trailing flank of reflectivity. This is indication that RIJ is penetrating back side of the bow toward the leading edge.

This portion of the QLCS is the most likely segment to attain balance and sustain vertically erect updrafts that can be stretched.

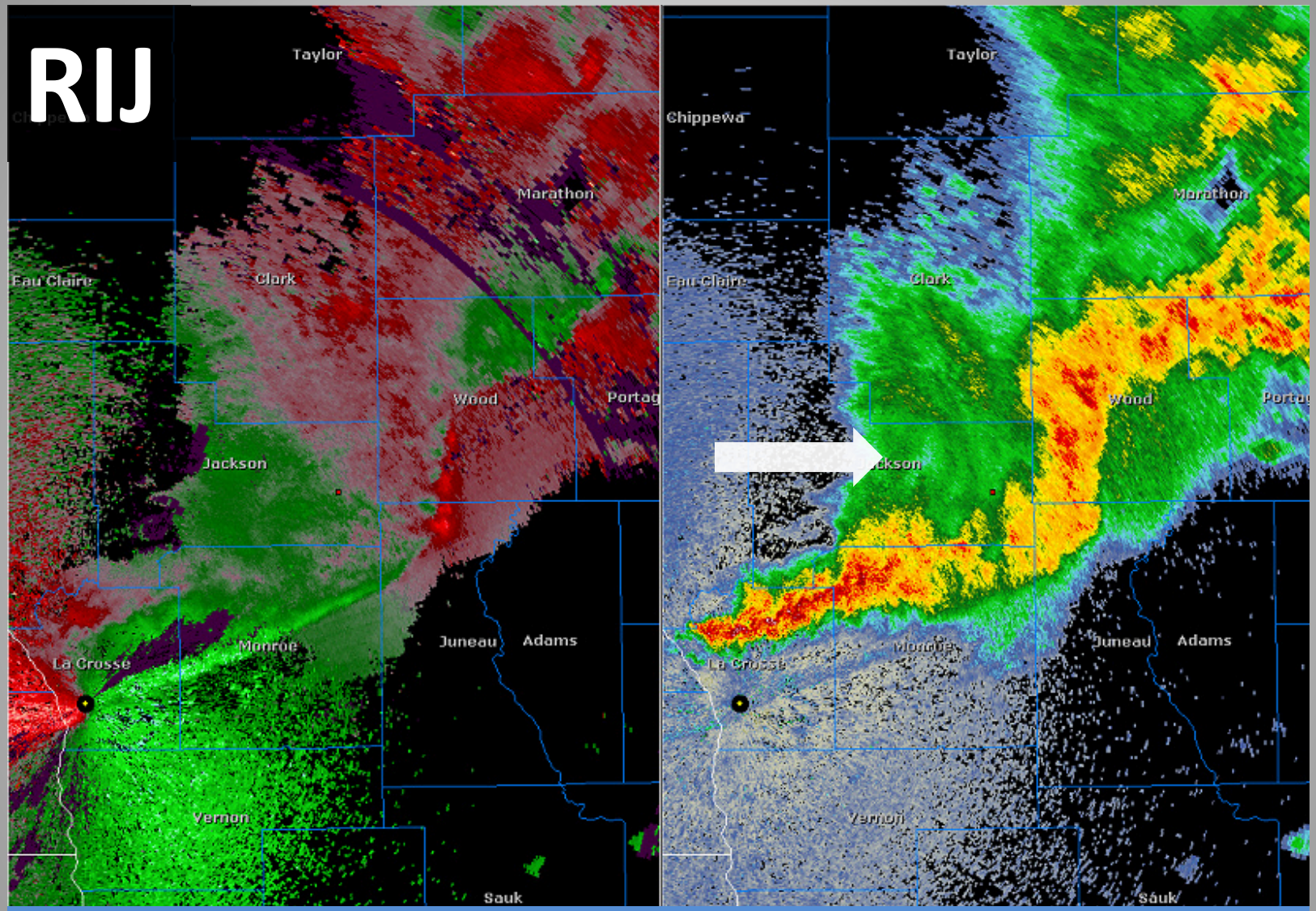


Portion of line segment rotated N-S and became nearly perpendicular to the 0-3 km bulk shear vectors.

Weak MVs form as line surged/pivoted.

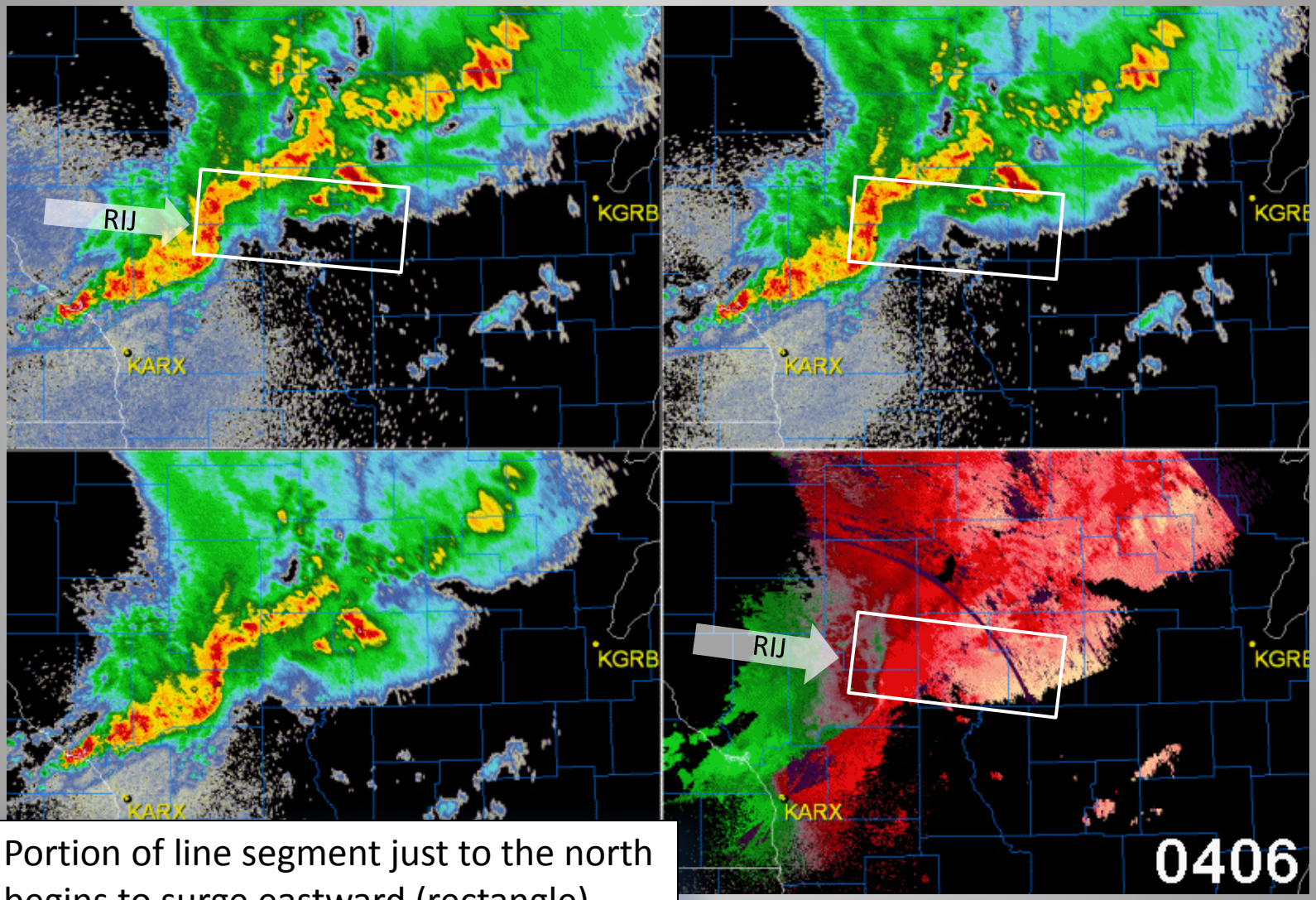


Downstream shear vectors (circled) suggest ~ 30 KTS 0-3 KM shear (RAP)



Although radar viewing angle not ideal, presence of RIJ was evident

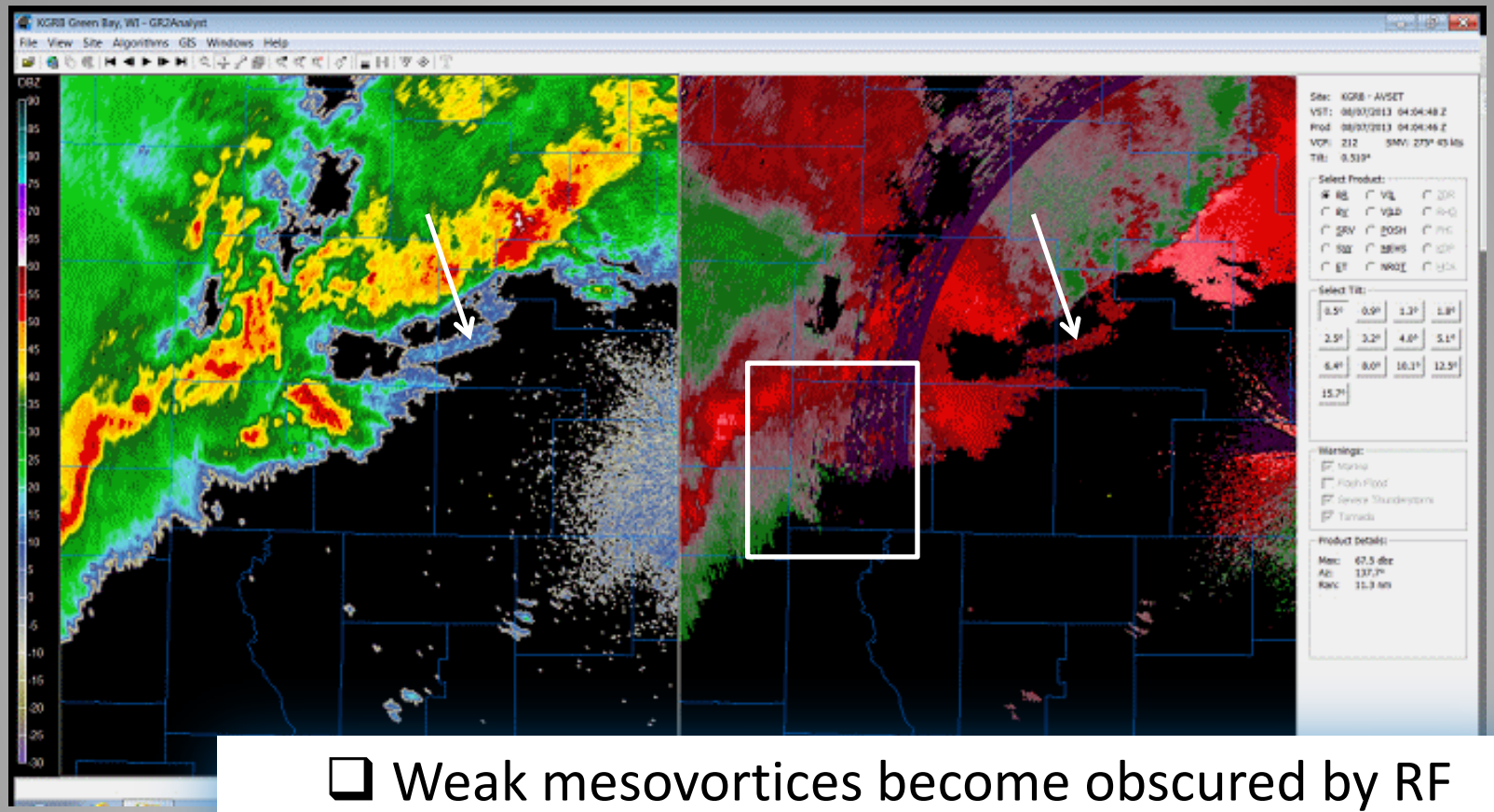
RIJ



Portion of line segment just to the north begins to surge eastward (rectangle)

Preliminary observations of early episode of MV formation

- Initial mesovortex (MV) evolution occurred between ARX and GRB. Radar sampling poor.
- Could not accurately determine MV evolution & structure beyond 50 nm due to radar sampling limitations .
- It appeared line segment was balanced. MVs formed and remained anchored to leading updraft-downdraft convergence zone (UDCZ).
- After initial MV formation, subsequent MVs formed to the north.
- Given sampling limitations, it “appeared” that these mesovortices were weak and shallow (except MV1)
- Only a handful of wind damage reports. Appeared most of the wind damage was associated with MV1. MV1 also appeared to be the most persistent.
- No formal damage surveys conducted in associated with first mesovortex phase. Do not know with certainty if additional wind damage or tornadoes may have occurred.

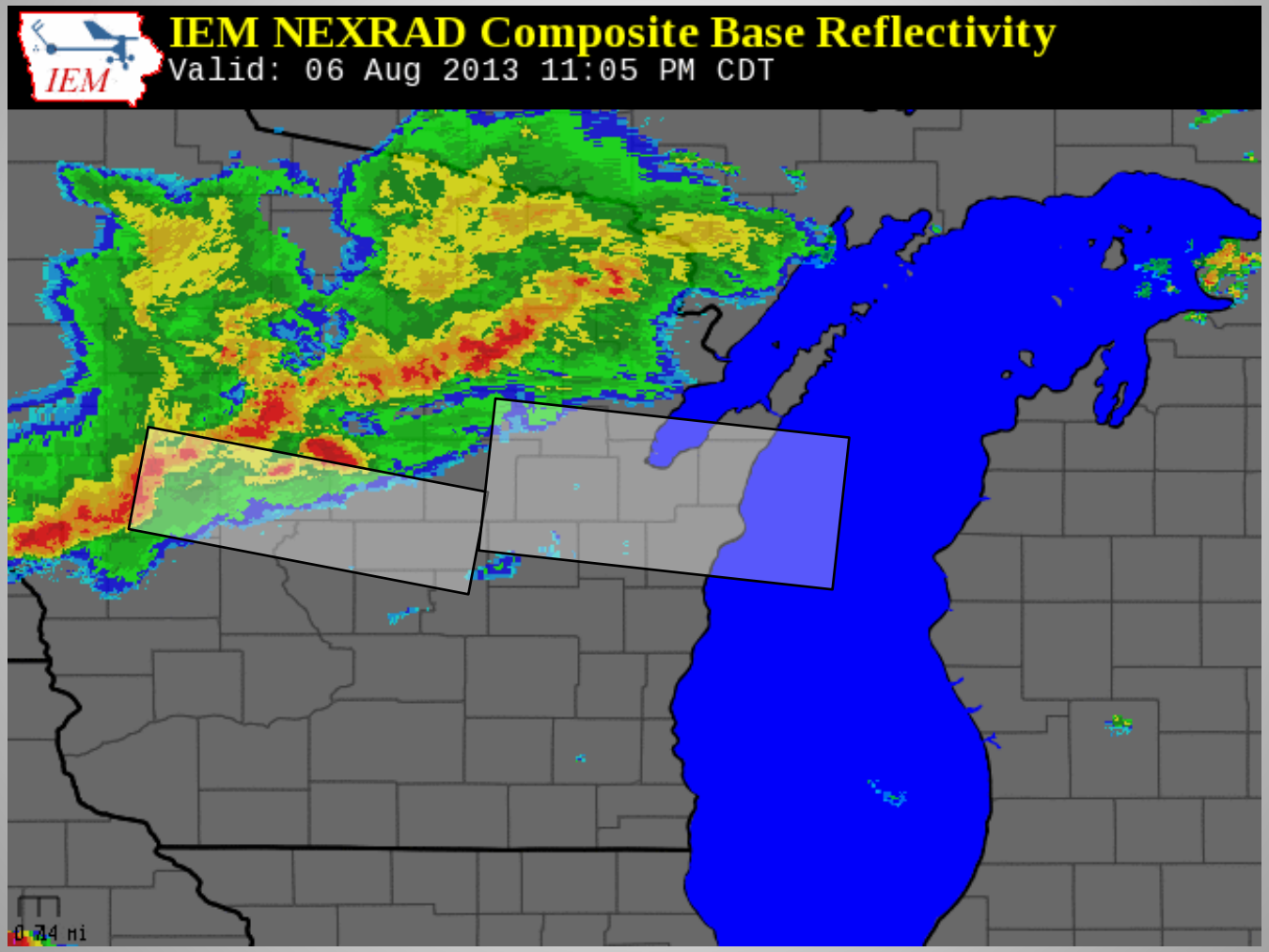


- ❑ Weak mesovortices become obscured by RF
- ❑ Inadequate sampling of initial “weak” MVs upstream. Between ARX/GRB radar.
- ❑ Outflow dominant portion of QLCS to the north surges southward.
- ❑ RIJ is present

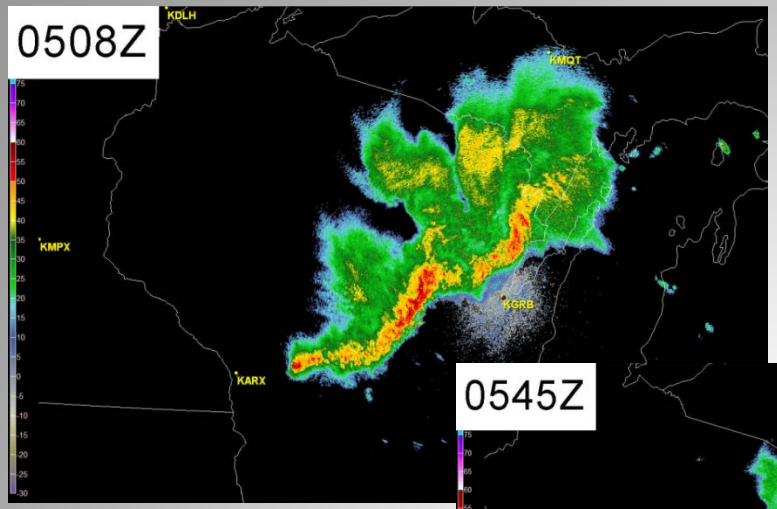
Situational Awareness

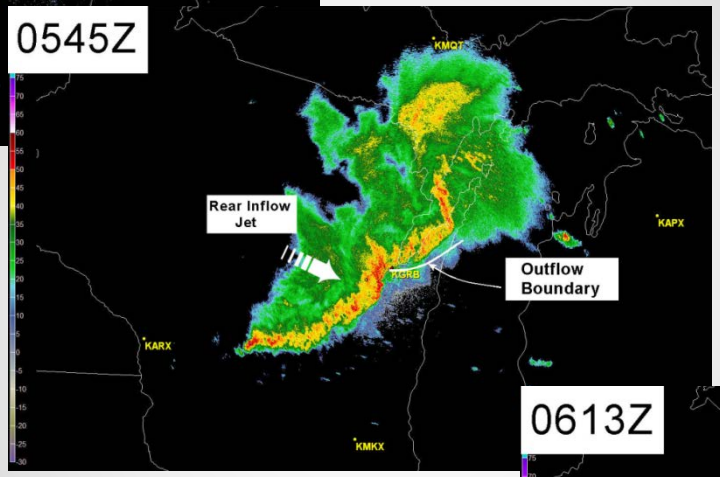
- Initial focus on marginally severe storms (N-NW of GRB) as they moved into the forecast area first.
- Initial mesovortices form upstream. Become obscured by RF.
- Line segment further north begins to surge in response to rear inflow jet (RIJ).
- Outflow dominant portion of QLCS drives boundary southward ahead of surging portion of QLCS.
- No recent severe reports. Reinforced perception of low-level nocturnal stabilization and a minimal severe wind threat.

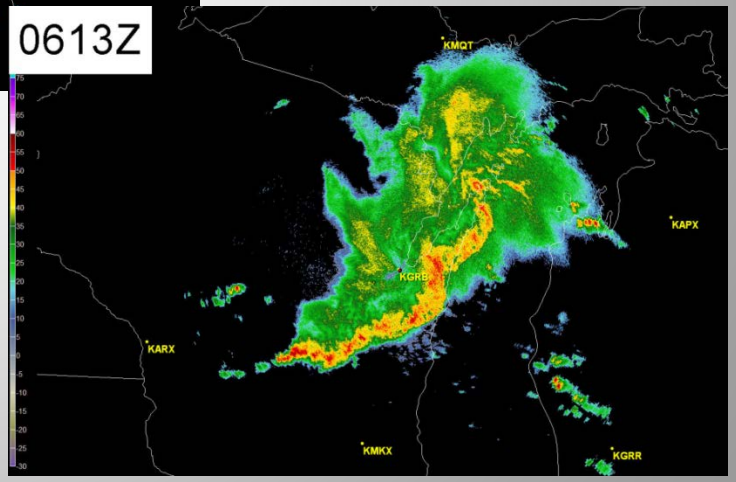
Tornadic Mesovortex Formation Over the Fox Valley



Mesovortex Episode 2
05Z–07Z



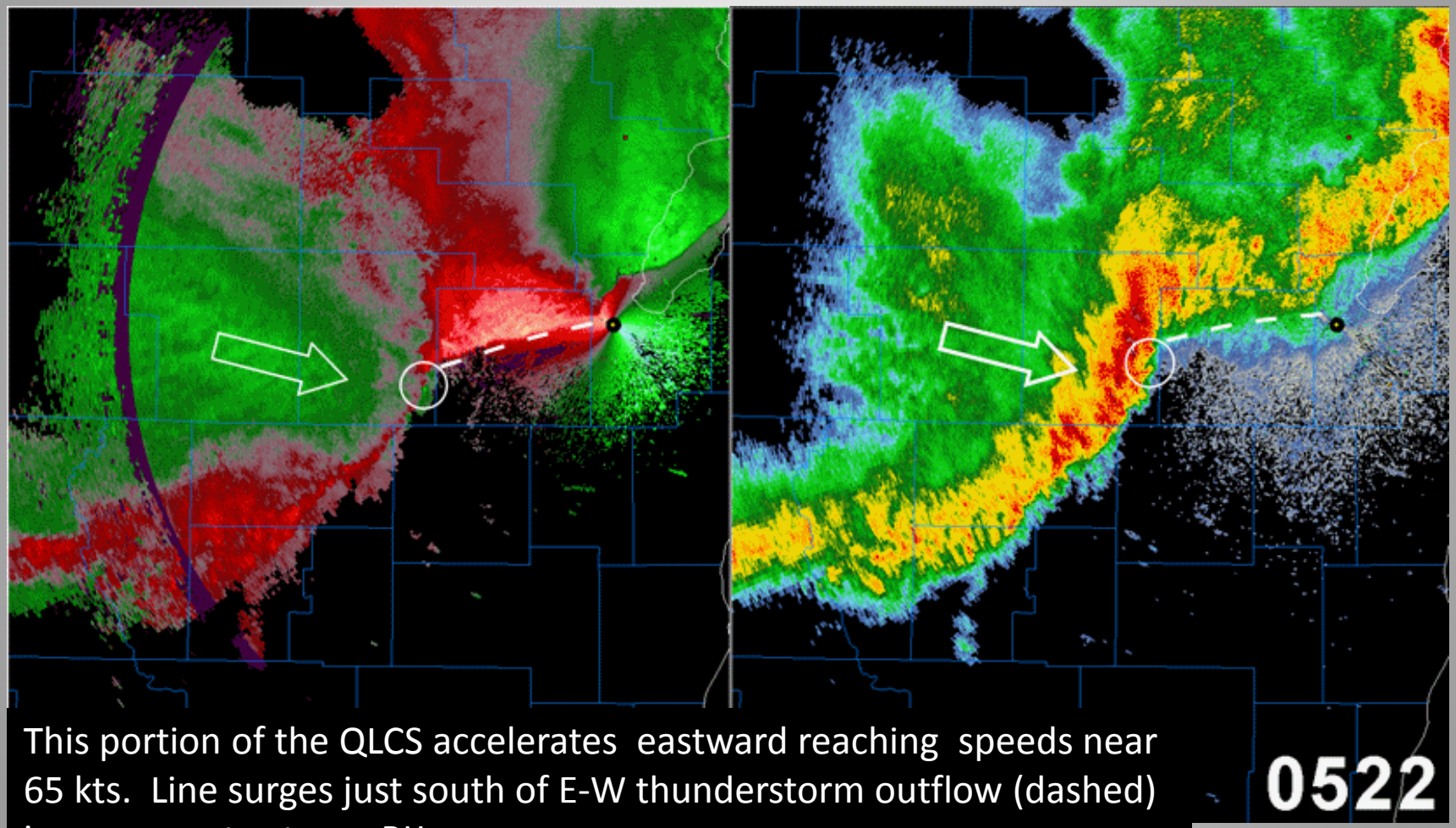




- Mature RIJ
- Second line surge occurs just north of the previous one.
- Surge occurs just south of E-W thunderstorm outflow boundary.

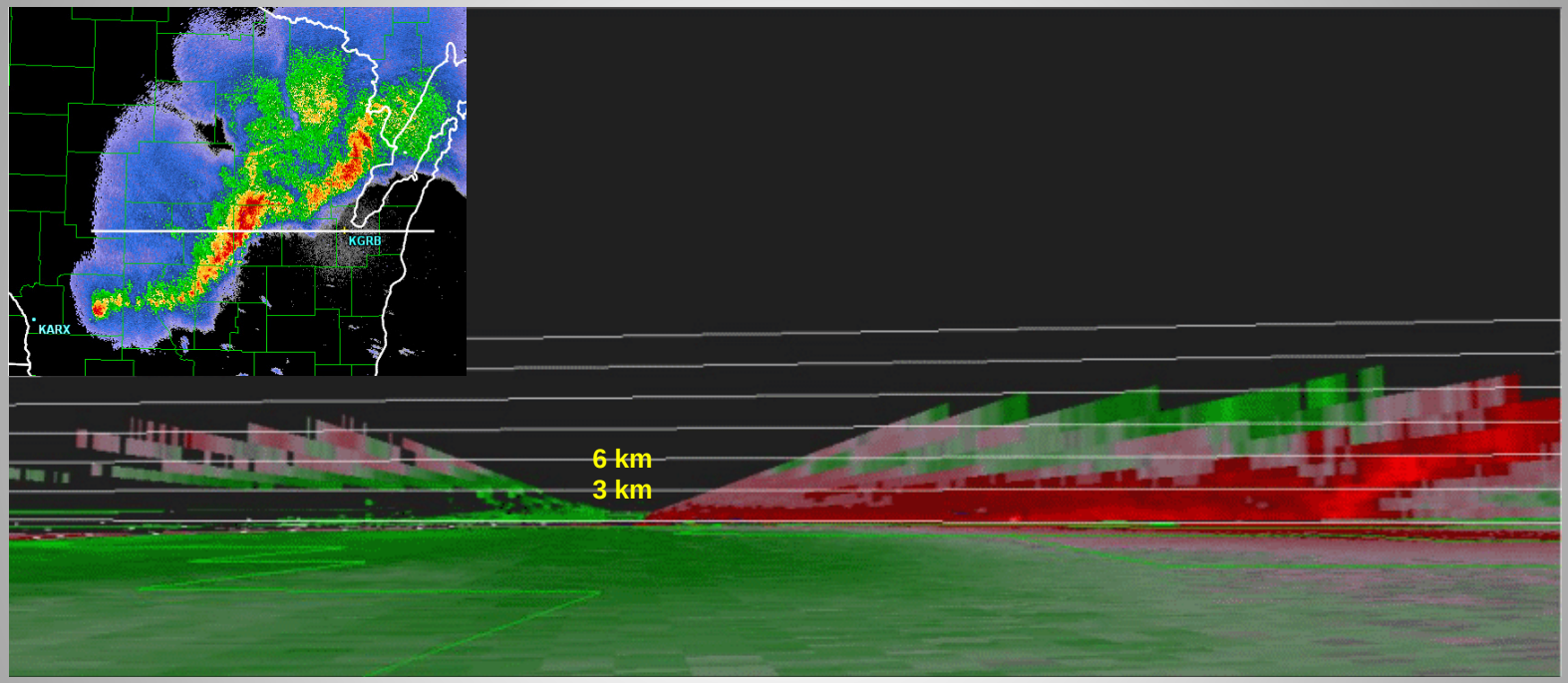
- MVs form roughly between bow apex and boundary.
- MVs intensify very rapidly and become tornadic.
- Line segment accelerates to 65 KTS.

Radar Evolution

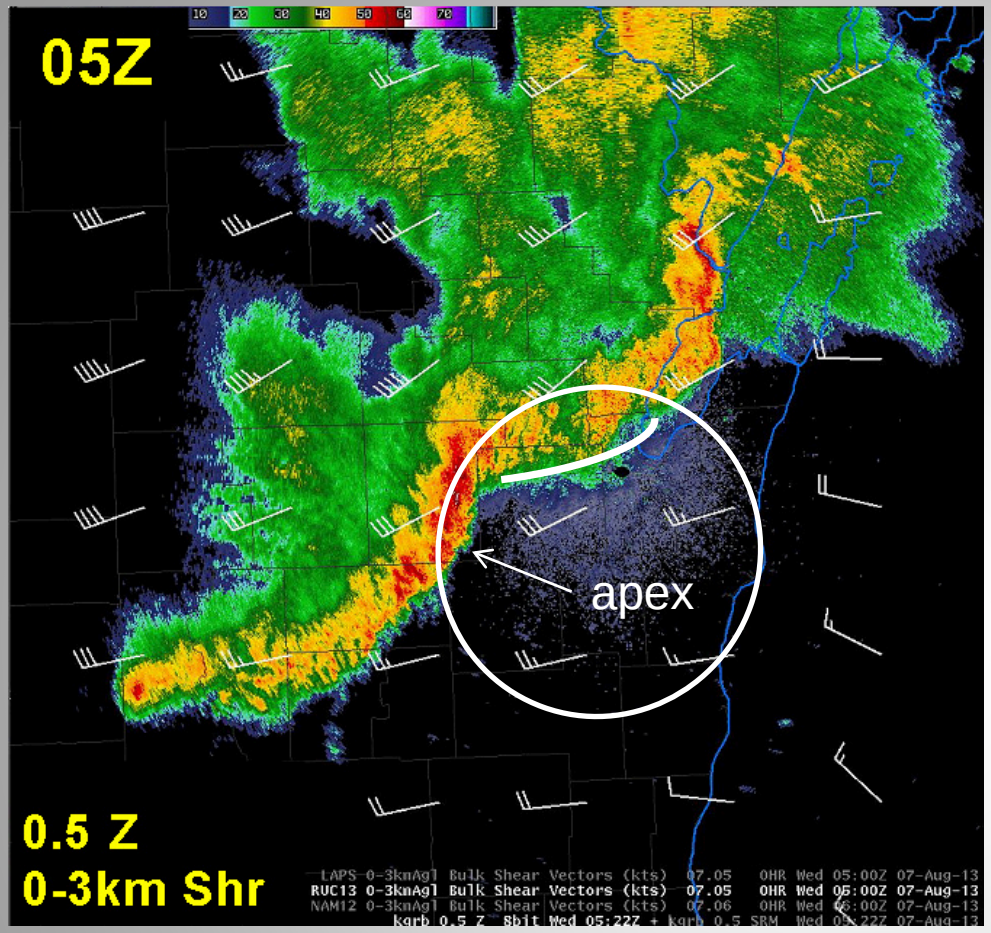


This portion of the QLCS accelerates eastward reaching speeds near 65 kts. Line surges just south of E-W thunderstorm outflow (dashed) in response to strong RIJ.

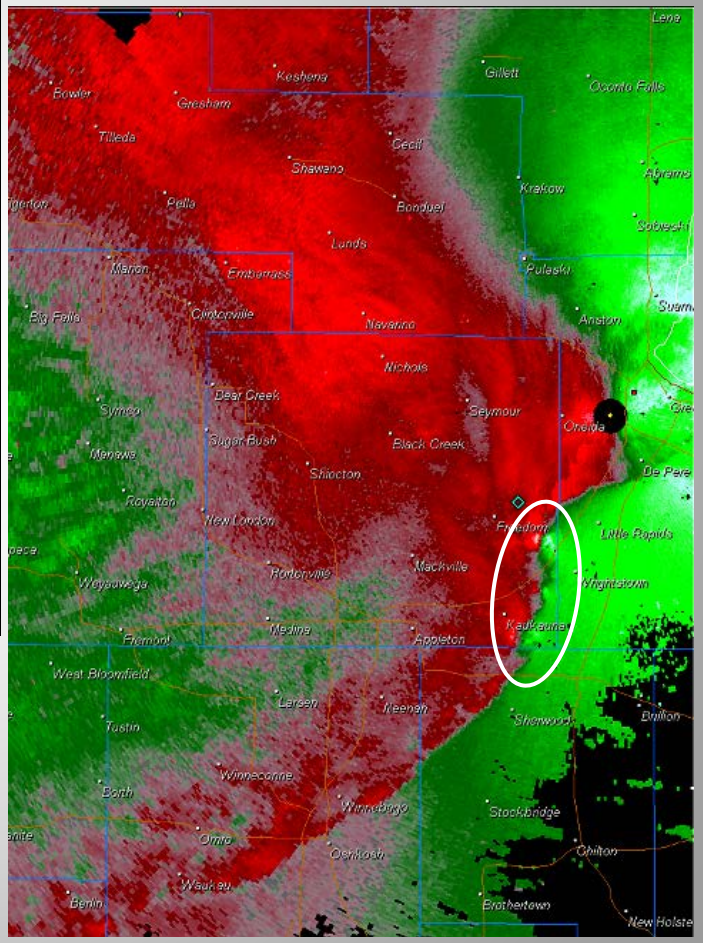
GRB SRM Cross-Section (Looking South)
0508 UTC – 0613 UTC



SRM cross-section (animation) illustrating RIJ and UDCZ on leading edge. RIJ and UDCZ primarily below 6 km.



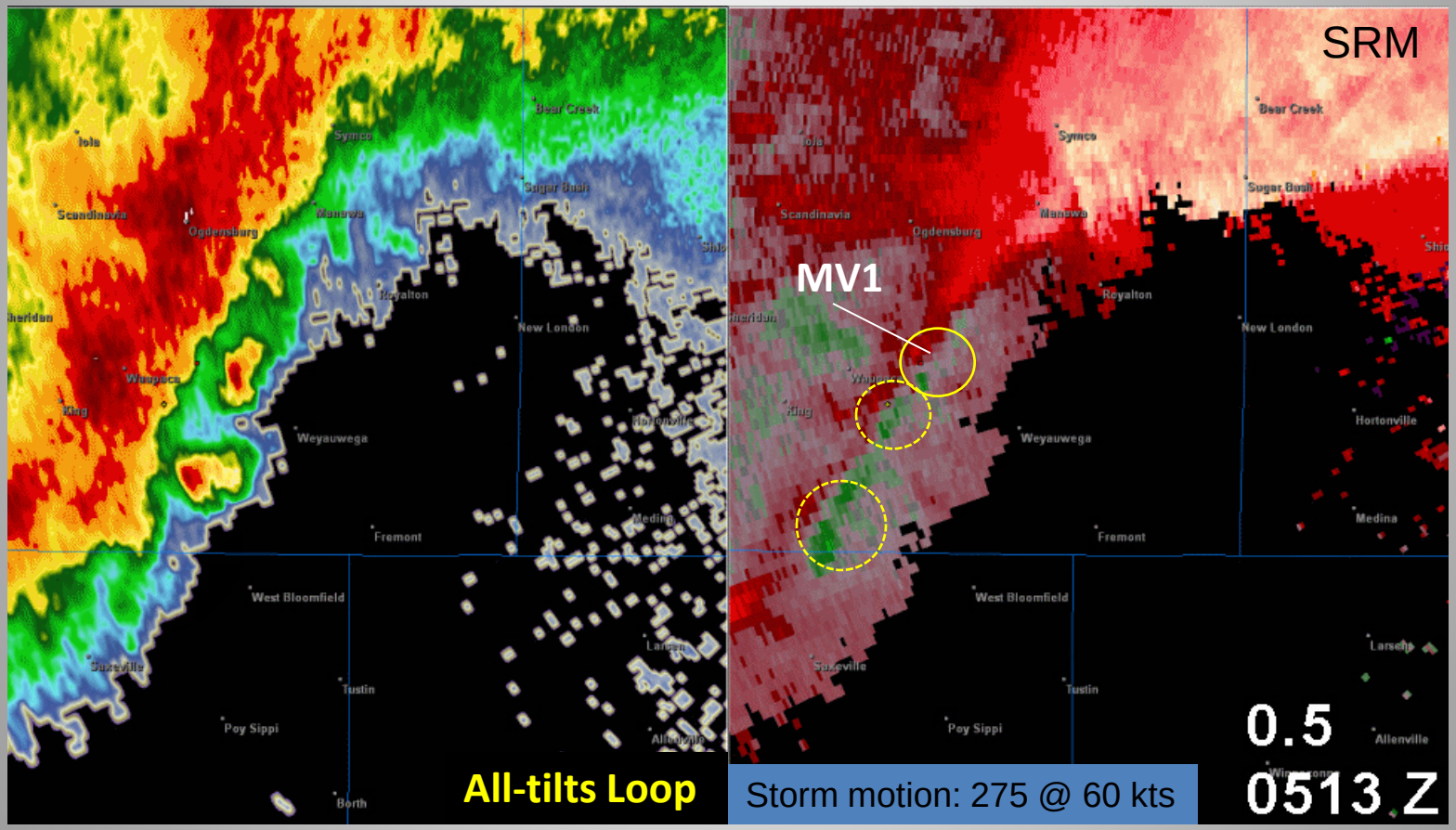
Mesovortices develop once again as line segment surges and pivots to N-S orientation. Becomes more favorably aligned to 0-3 km shear vectors. Note RAP shear magnitudes may be underestimated.



This segment of the QLCS most likely to be balanced. Tornadic MVs form generally in 30 mile corridor bounded by bow apex to south and thunderstorm outflow boundary to north.

Radar Evolution

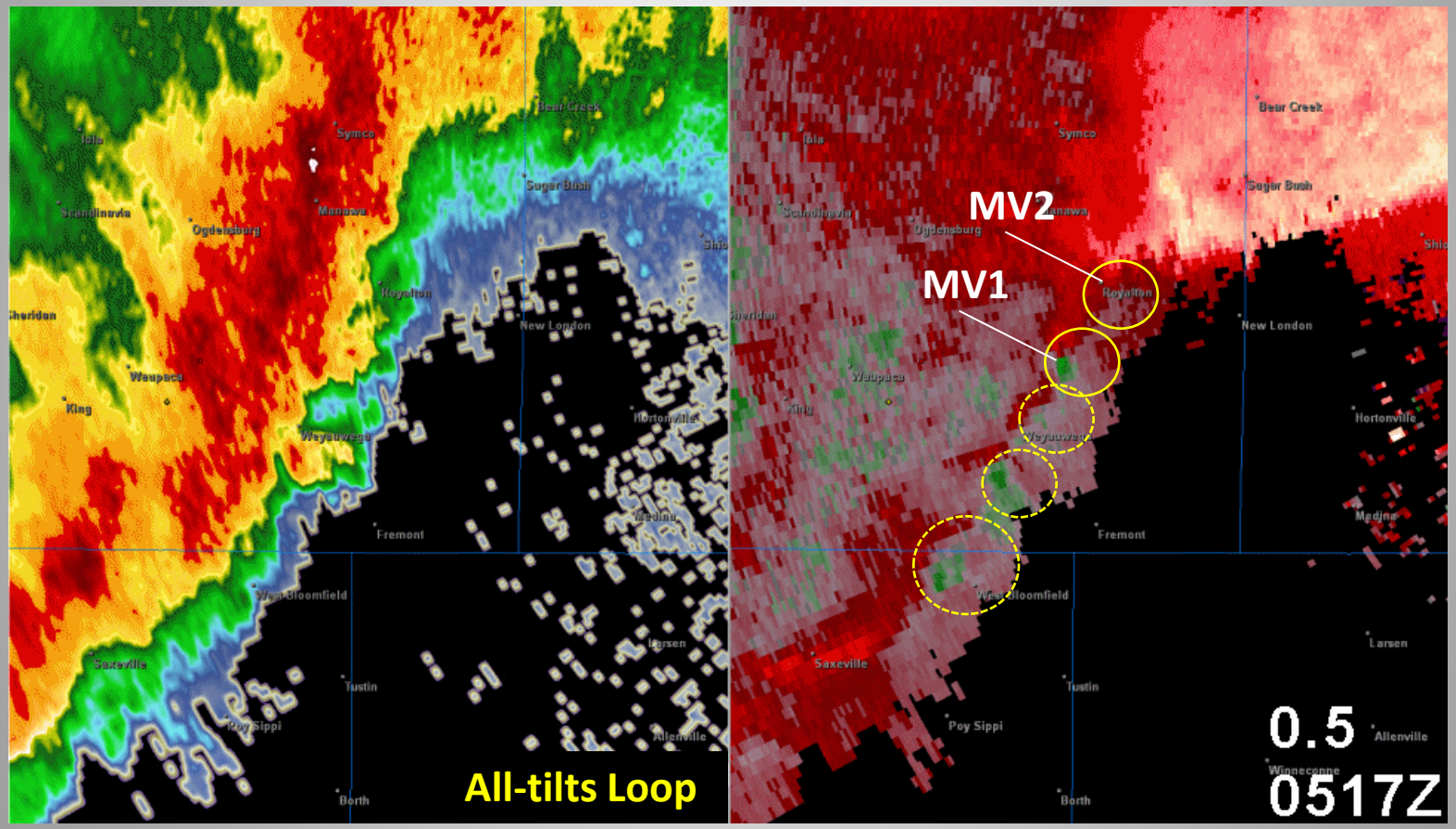
Initial Tornadic Mesovortex (Genesis)



Note the isolated cells just ahead of the leading edge of solid line echo in the reflectivity image on the left. These reflect the <u>multicell evolution of the system</u>. Note how they merge with the leading edge in subsequent volume scan (next slide)

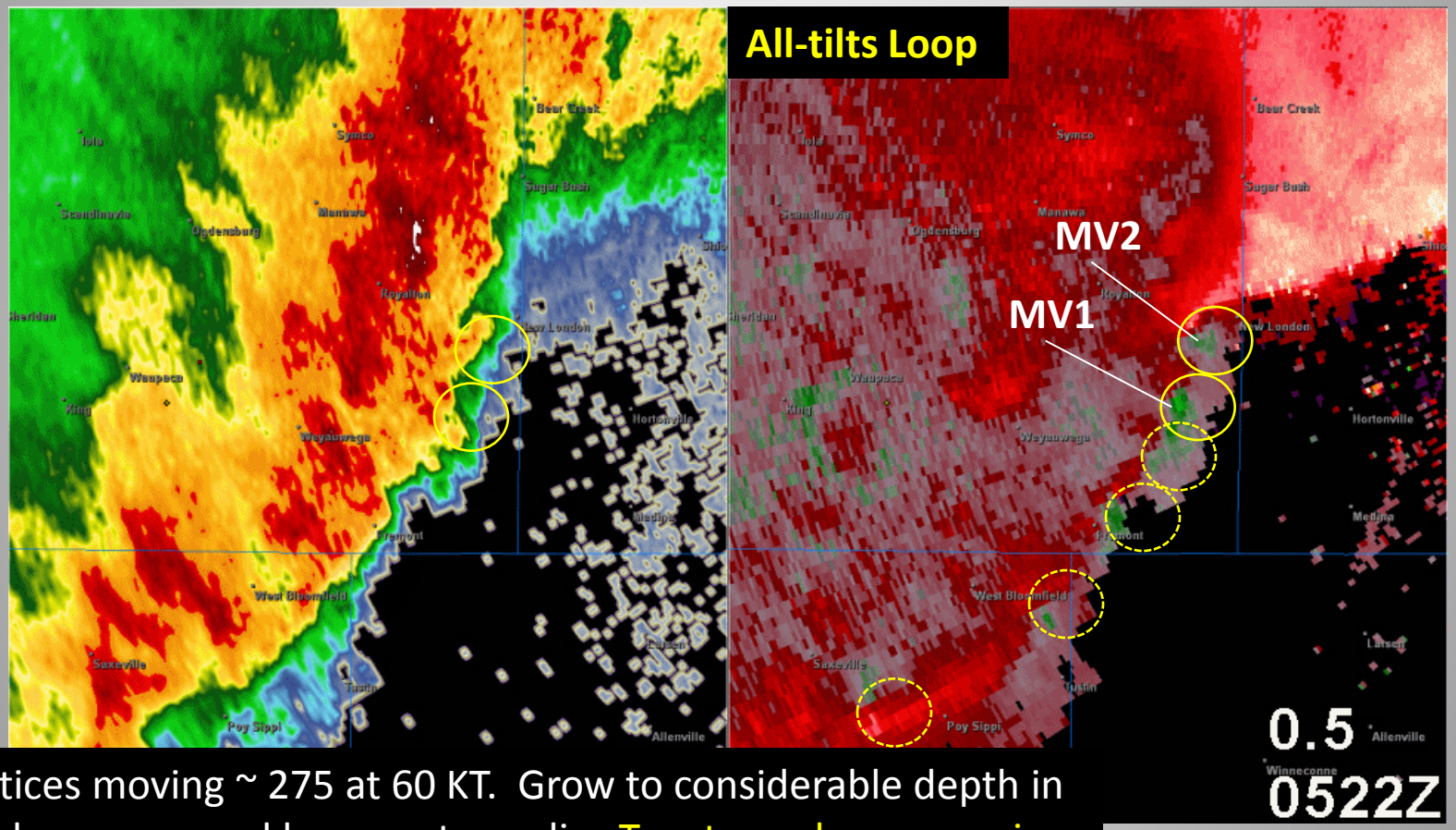
Radar Evolution

Initial Tornadic Mesovortex (T-1 Volume Scan)

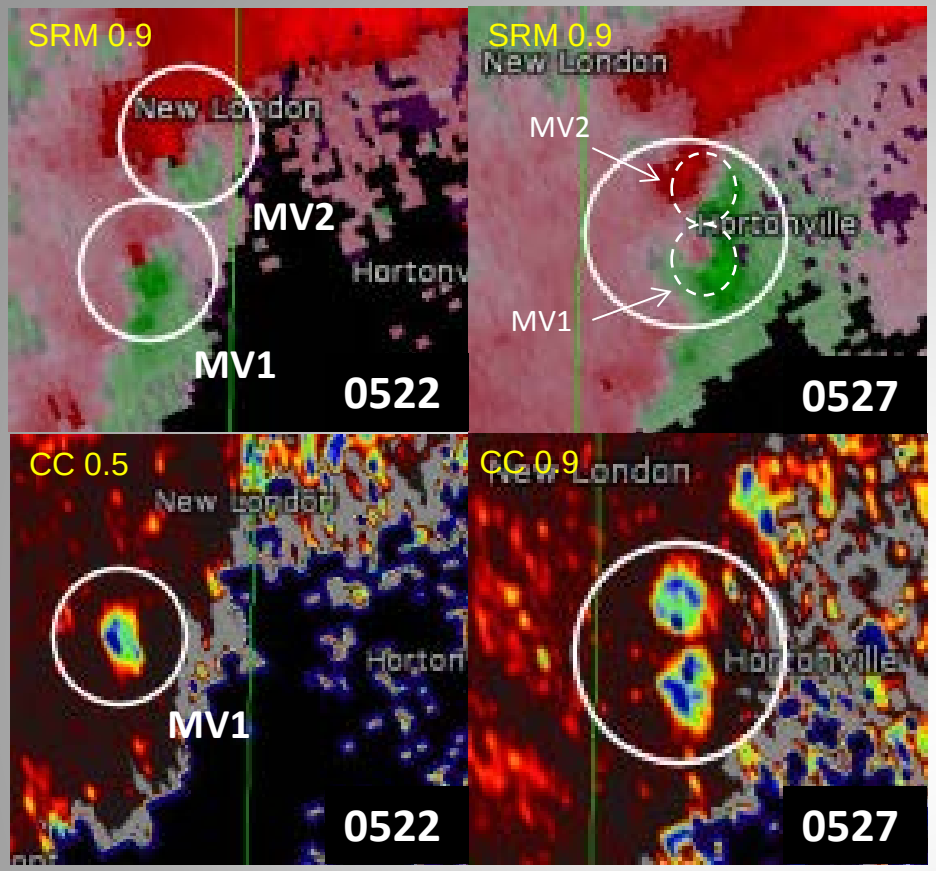


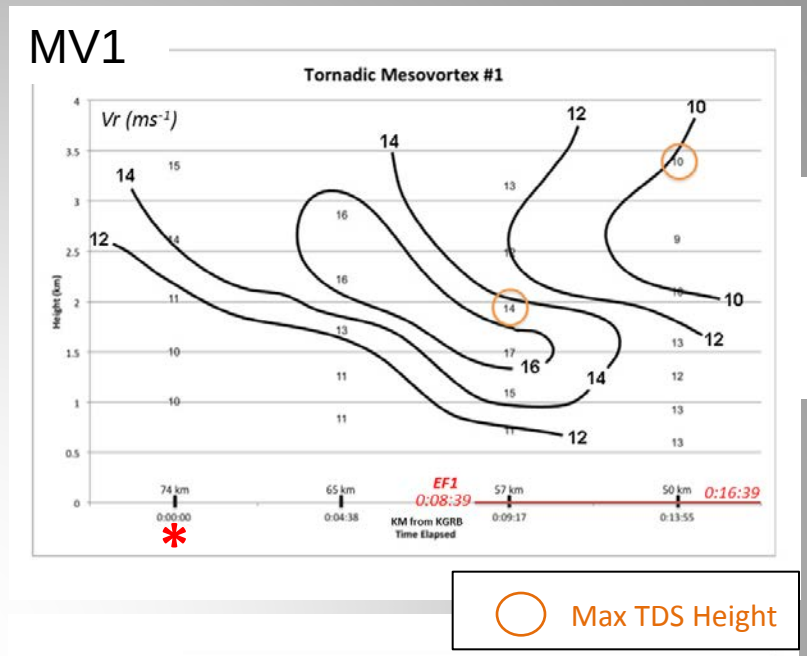
Radar Evolution

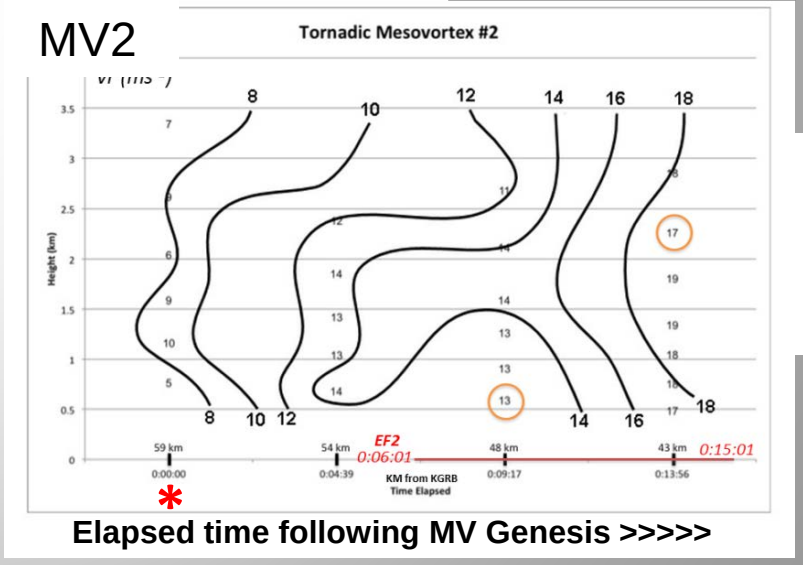
Tornadogenesis



Vortices moving ~ 275 at 60 KT. Grow to considerable depth in 1 volume scan and become tornadic. Two tornadoes occurring around this time (solid circles).





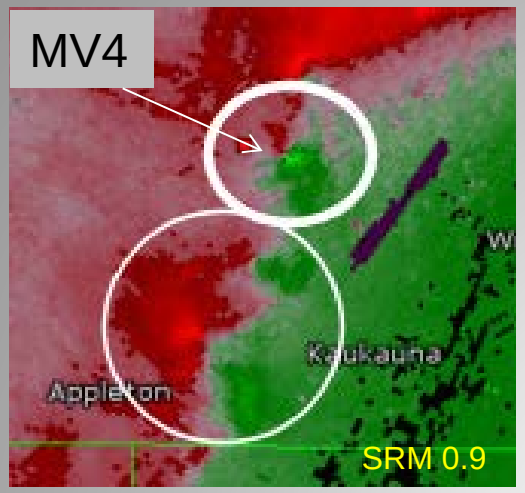


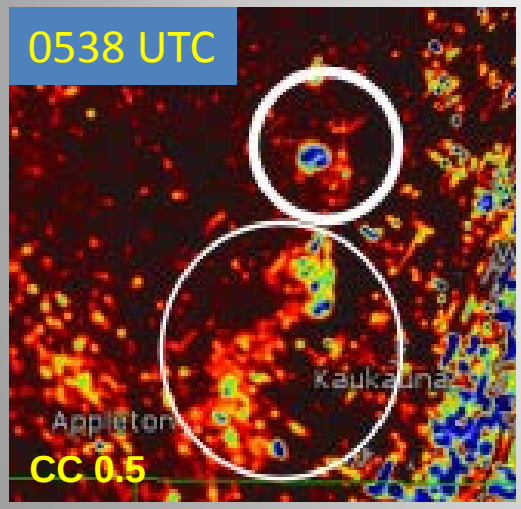
Time from MV genesis to TDS ~ 2 Vol Scans

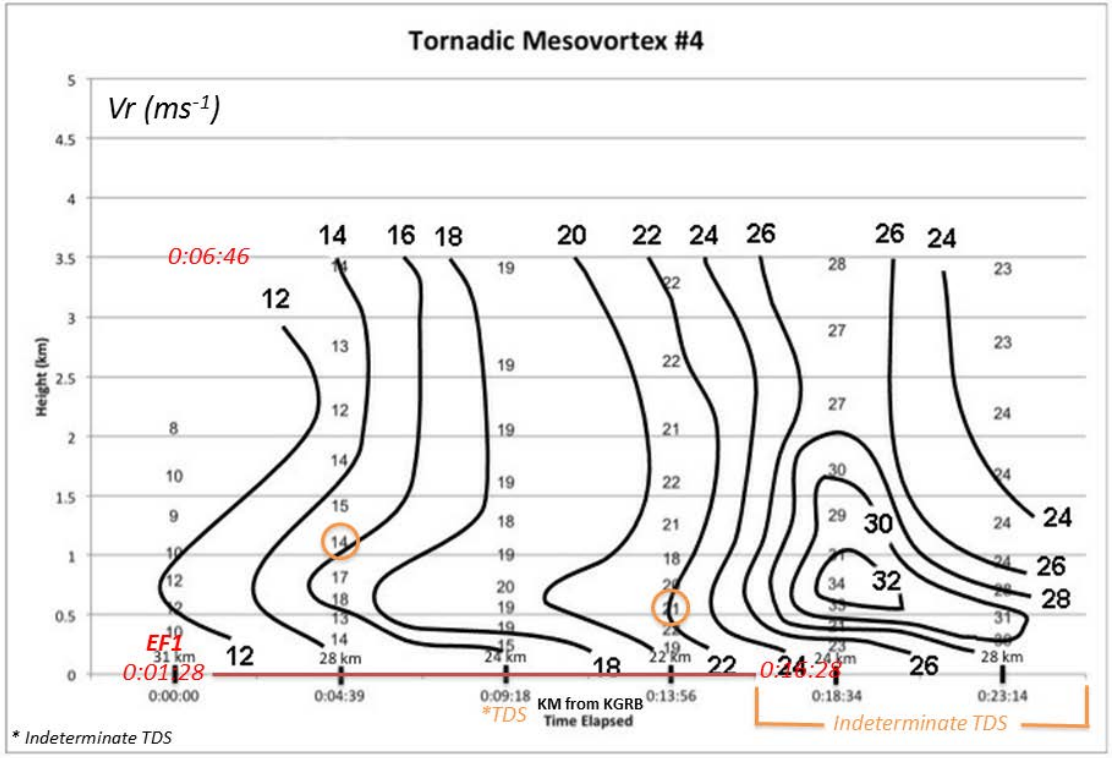
MV1 – Max initial TDS Height ~ 2 KM
MV1 – Max TDS Height ~ 3.5 KM
MV2 – Max initial TDS Height ~ 0.5 KM
MV2 – Max TDS Height ~ 2.25 KM

MV1 & MV2 eventually merge.

* **Time of initial MV Genesis**



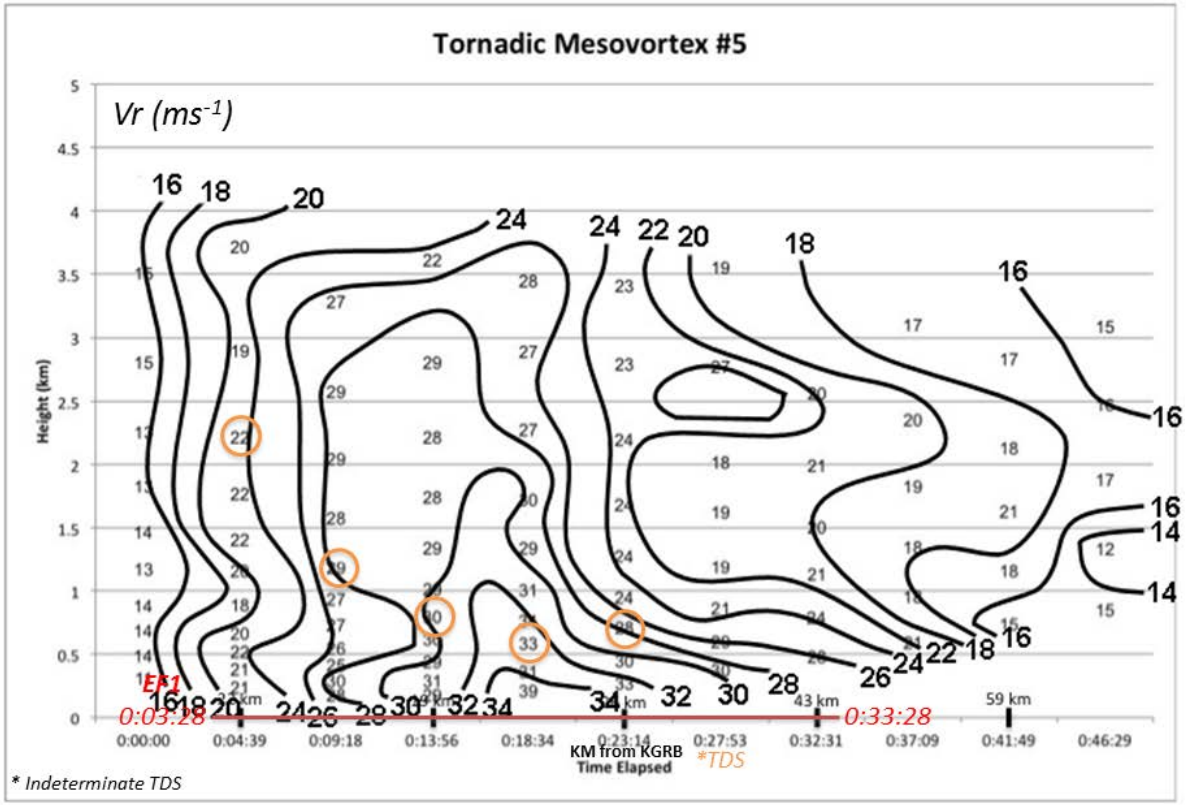




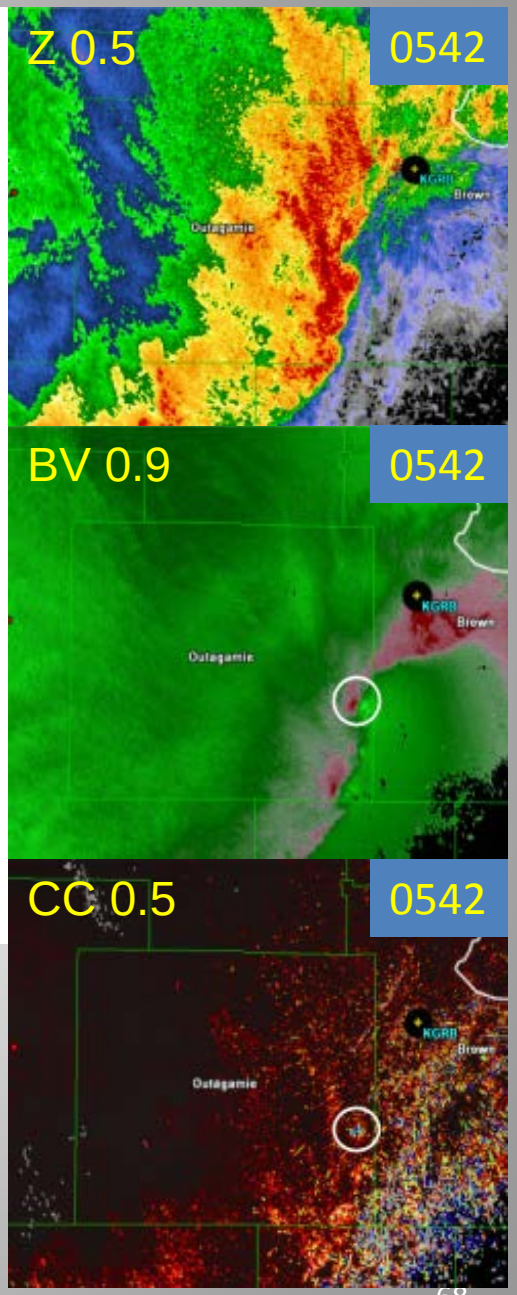
Elapsed time following MV Genesis >>>>>

More rapid evolution associated with MV4

Time from MV genesis to TDS ~ 1 Vol Scan
Max initial TDS Height = Max TDS Height ~ 1 KM

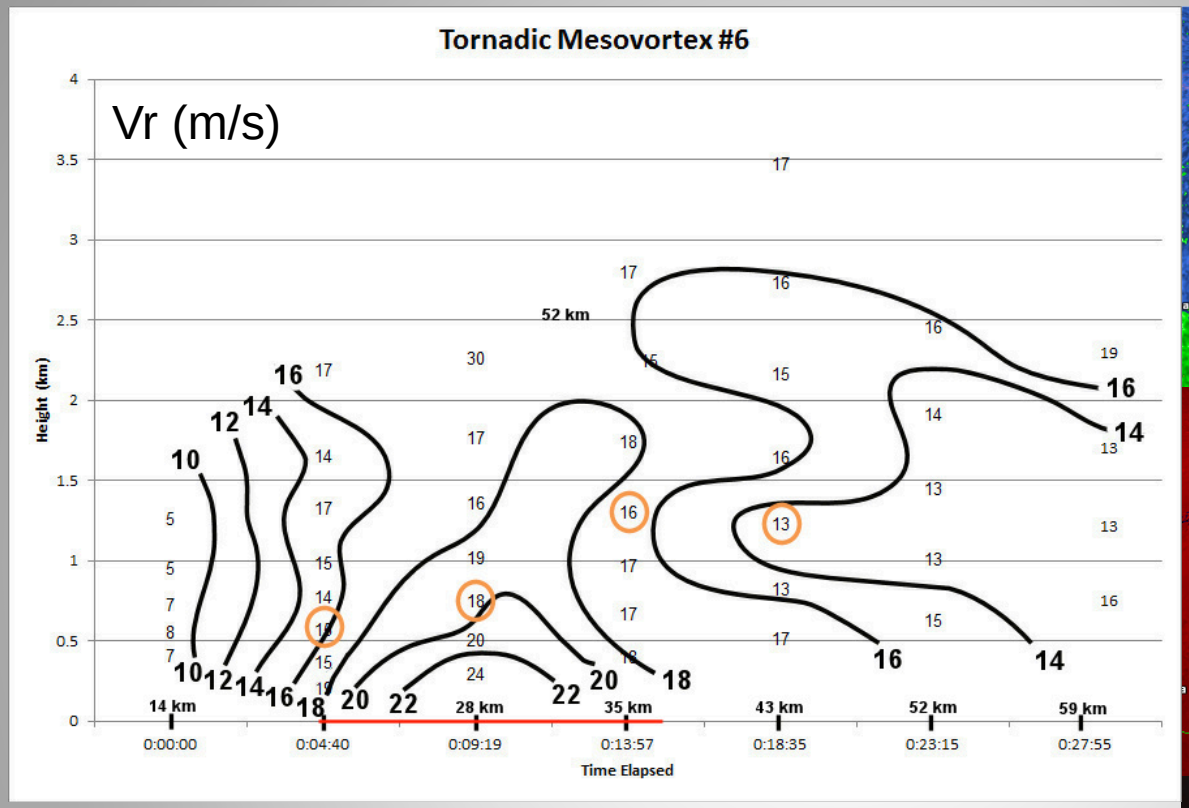


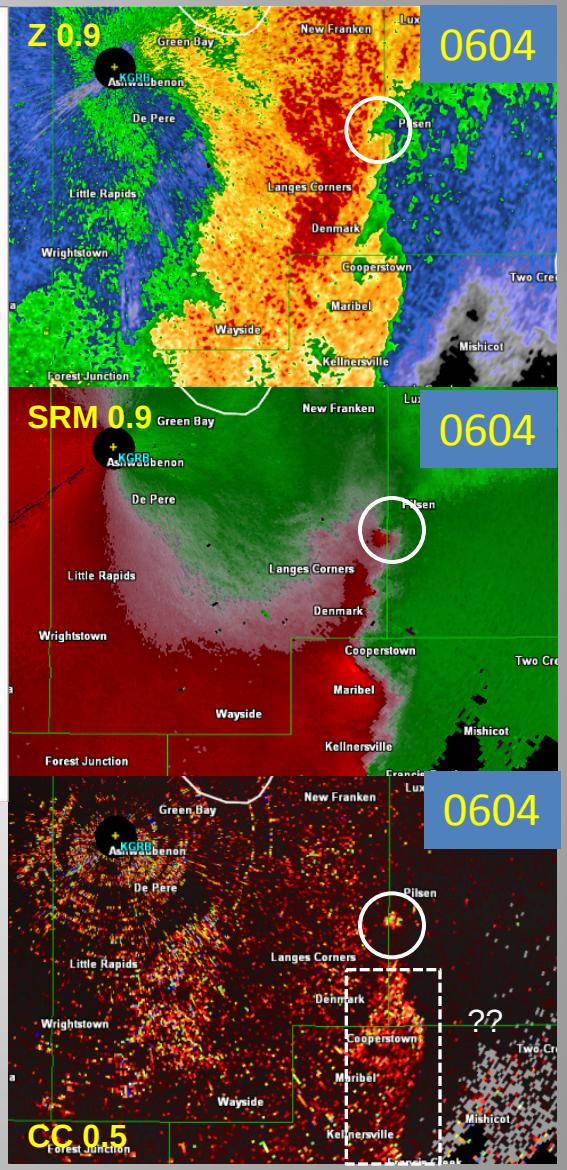
Elapsed time following MV Genesis >>>>>



MV5 appears to develop on or just south of boundary.
Time from MV genesis to TDS ~ 1 Vol Scan. **<u>Very rapid</u> evolution!!!**
Classic ND characteristics. Appeared to be the strongest MV.

Max initial TDS height = Max TDS Height ~ 2.25 KM

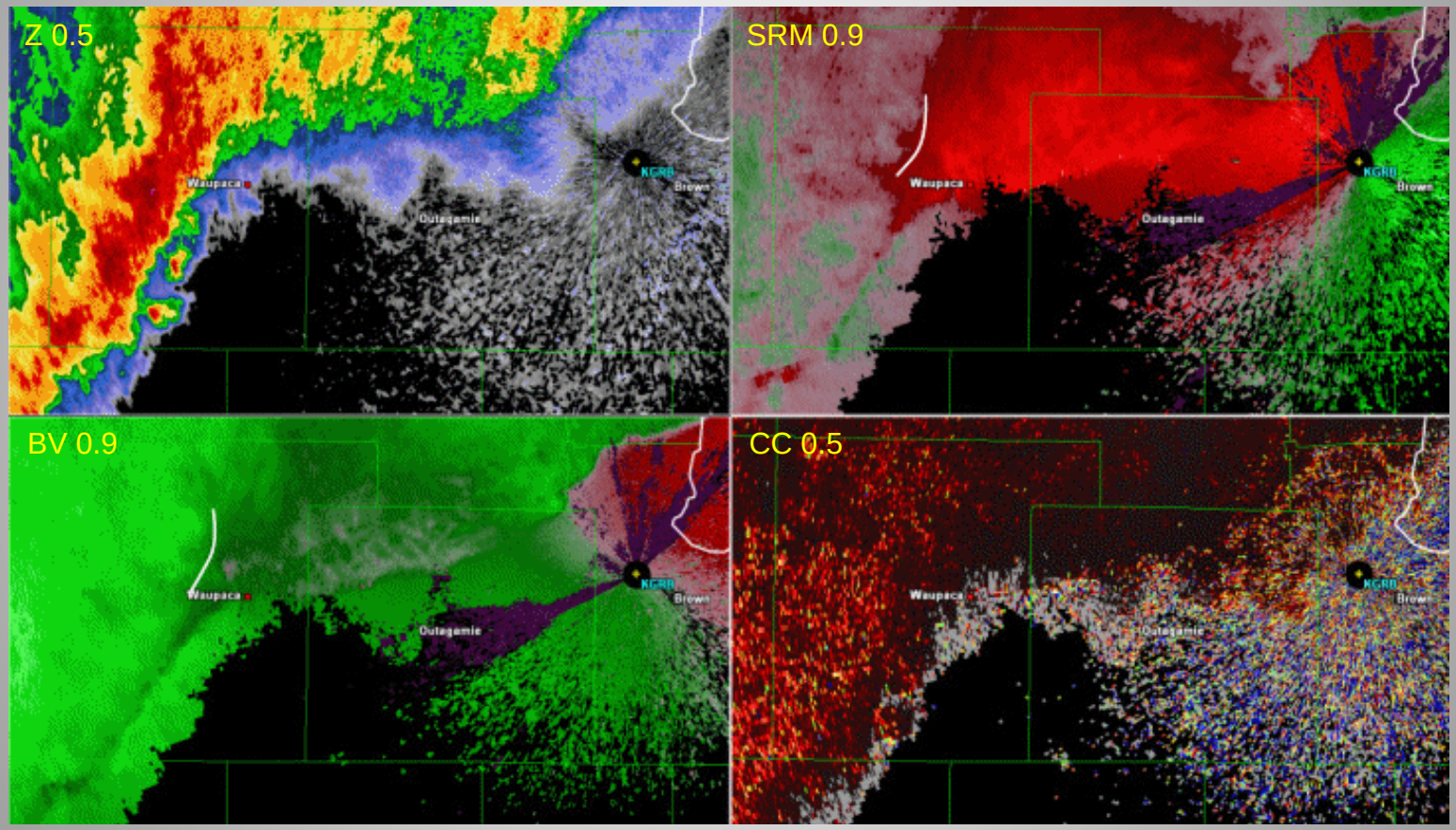




Time from MV genesis to TDS ~ 1 Vol Scan. MV6 forms on boundary. Classic ND Vr characteristics once again.

Max initial TDS Height ~ 0.5 KM
Max TDS Height ~ 1.5 KM

RIJ surge associated with MV5 tornadogenesis?



Recall 3rd co-existing ingredient from Schaumann and Przybylinski (2012)

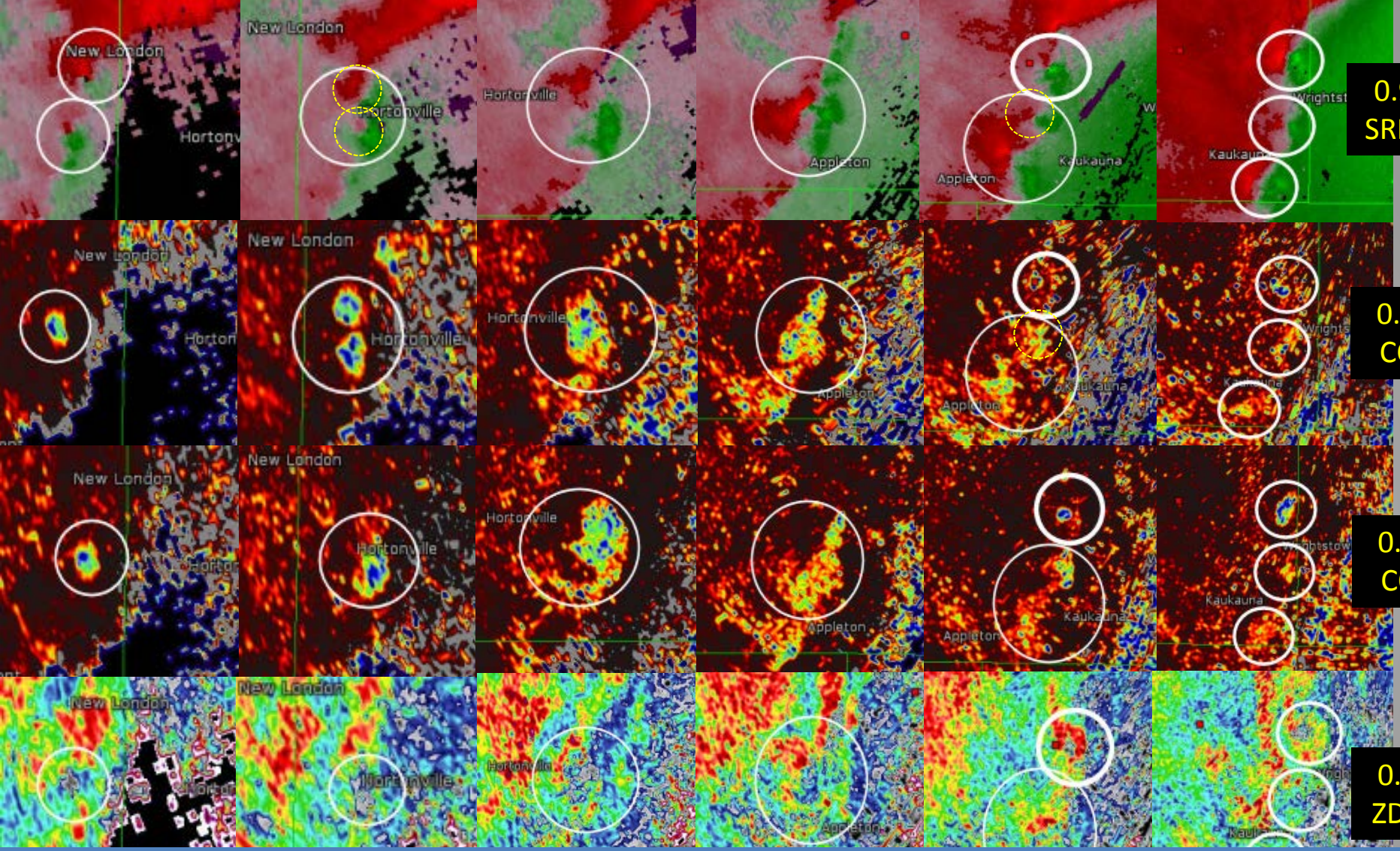
Some Very Preliminary Observations Tornadic Mesovortices

- MV genesis occurred in balanced segment of QLCS. MVs anchored to leading UDCZ during lifetime.
- Evolved within relatively narrow corridor bounded by the bow apex to south and outflow boundary to north. All evolved $\leq$ 40 nm from Radar.
- Some tornadic MVs associated with RIJ surge (e.g., MV5)?
- Subsequent mesovortices developed to north (MV family).
- MV2, MV5 and MV6 developed either on or just south of the boundary.
- Developed/evolved very rapidly. Very rapid vertical growth indication of strong/intense updraft (stretching of vortex tube).
- Non-descending characteristics
- Sometimes very difficult to follow evolution between subsequent volume scans due to close proximity of individual MVs, MV mergers, rapid vertical growth and rapid forward propagation speed (even after the fact).

Some Very Preliminary Observations Tornadic Mesovortices

- Max rotational velocity (Vr) generally **AOB 1.5 km**
- Time from MV genesis to first observed TDS ~ **1 volume scan**
- Initial TDS observed **before** maximum Vr
- Mean maximum Vr ~ 26 ms^{-1}
- Mean maximum Vr at initial TDS detection ~ 19 ms^{-1}
- Average TDS depth ~ 2 km. Greatest TDS depth ~ 3.5 km (MV5)
- Max TDS depth observed in same volume scan in which TDS **first identified** in half the cases.

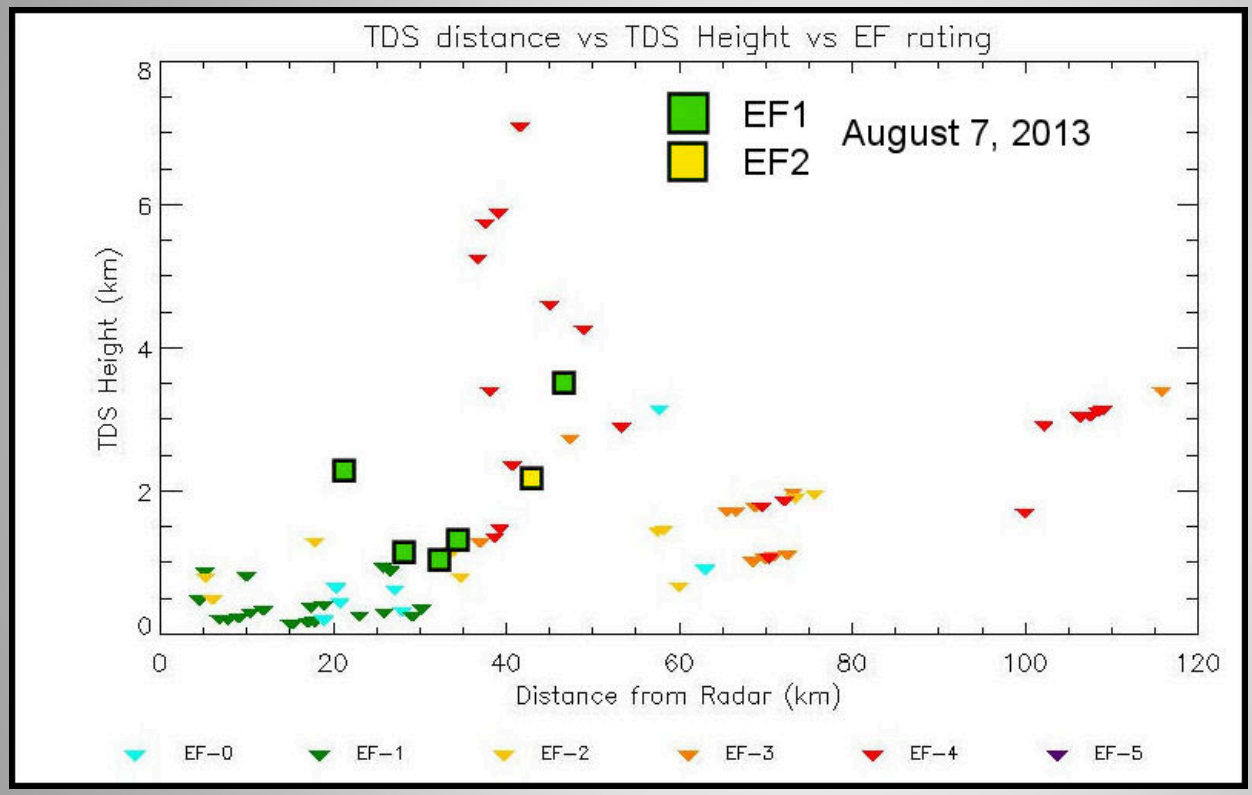
QLCS Mesovortices – Elusive and Sinister



TDS signatures became embedded within broader areas of relatively low CC near leading edge, making them difficult to identify at times. Are the broader areas of CC residual debris for tornadoes or perhaps light debris lofted at leading gust front or a combination??? Broad areas of relatively low CC observed later as system passed to the east of GRB (see slide 62 – 0604 UTC)

0522 **0527** **0531** **0536** **0541** **0545**

TDS Distance vs MAX TDS Height vs EF Rating
Includes Various Convective Modes (Alabama)



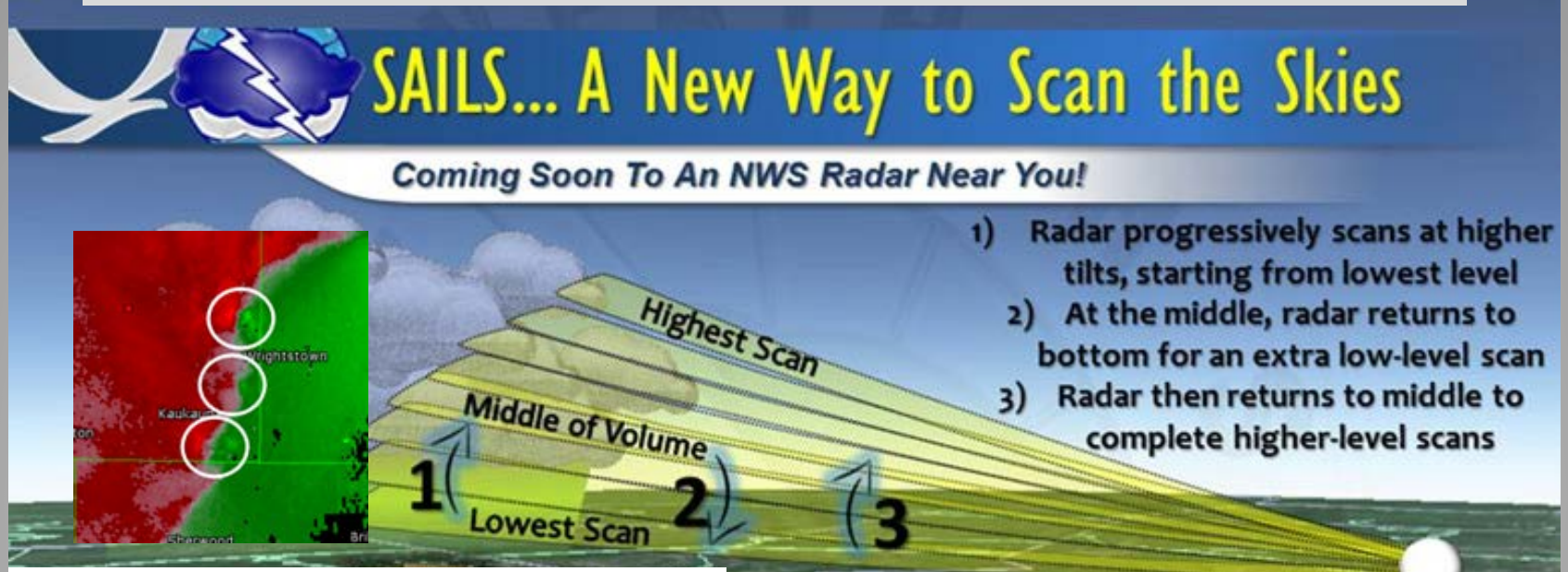
From Schultz et al (2012) – Their Figure 10.

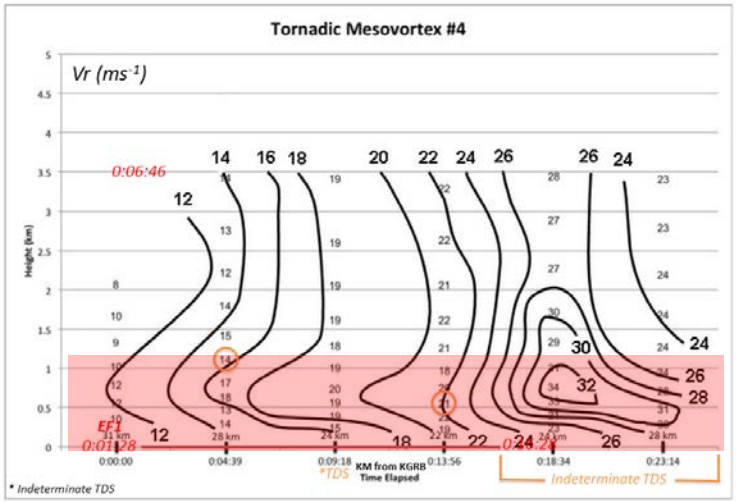
August 7, 2013

Max TDS heights observed in this event were comparable or slightly higher than EF1/EF2 tornadoes examined by Schultz et al (2012).

Still lots to learn about characteristics of QLCS debris signatures!

Supplemental Adaptive Intra-Volume Low-level Scan

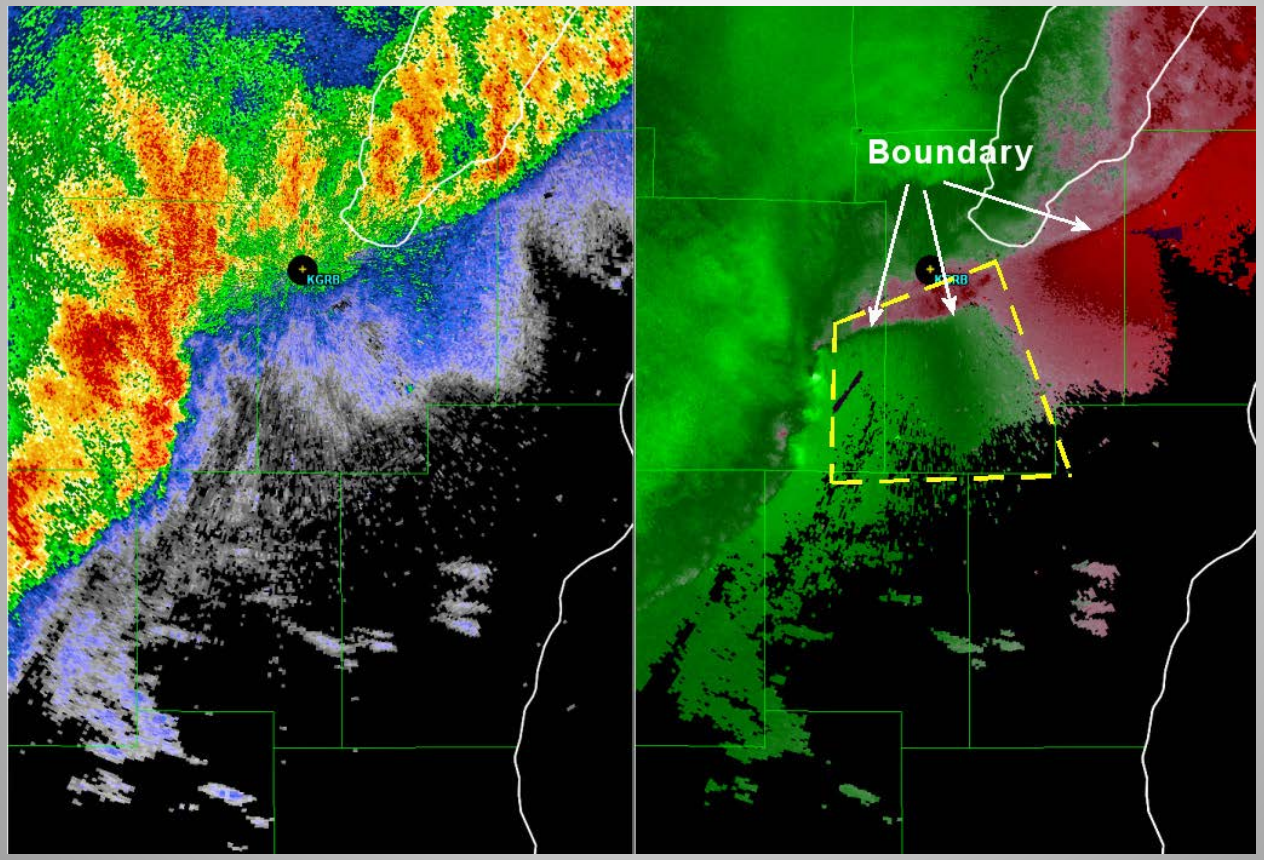




The radar scans different elevation "cuts" of the sky by changing its tilt after every revolution... giving a more complete view ("volume") of the sky!

How to best handle situation within the framework of the Storm-Based Warning (SBW) Methodology?

If tornadic MVs are suspected, consider (tornado) polygon encompassing all mesovortices if they are in close proximity (e.g., between bow apex and boundary).



2013 August 6-7 Early Morning Tornadic QLCS Over East-central Wisconsin

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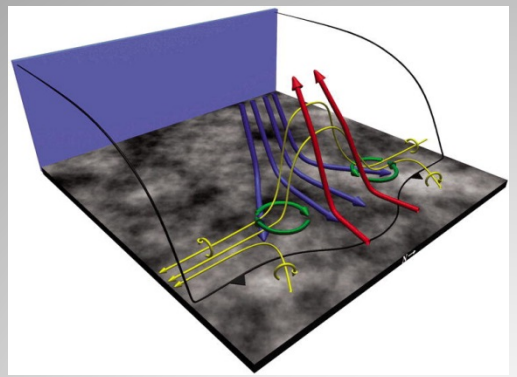
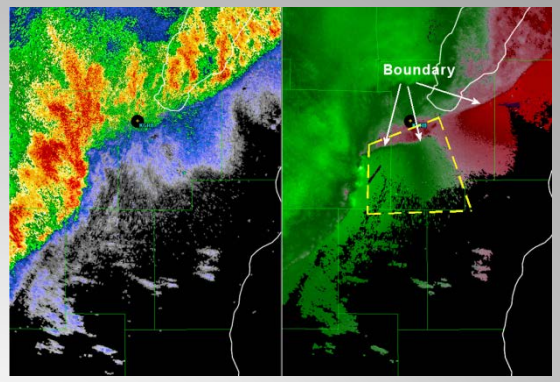
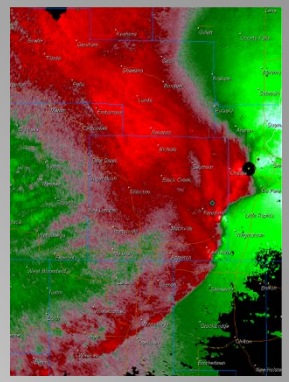
References:







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Schaumann and Przybylinski (2012) – Operational Application of 0-3 KM Bulk Shear Vectors In Assessing QLCS Mesovortex and Tornado Potential. Preprints, 26th Conf. on Severe Local Storms, Nashville, TN, Amer. Meteor. Soc., 9.10.

Schultz et al (2012) – Dual-Polarization Tornadic Debris Signatures Part I: Examples and Utility in an Operational Setting. EJOM., 13 (9), 120-137.

Schultz et al (2012) – Dual-Polarization Tornadic Debris Signatures Part II: Comparisons and Caveats. EJOM., 13 (10), 138-150

For more detailed information regarding the three ingredient method described by Schaumann and Przybylinski (2012), please also refer to the **Hollings Study Page** below:

http://www.crh.noaa.gov/sgf/?n=Hollings2013_MWS

Also, additional case studies illustrating the application of the three ingredient methodology can found here:

http://www.crh.noaa.gov/sgf/?n=0-3vect_paper

Thank You

Questions???