Overview of Storm and Vortex Morphology During the *'Intensifying Stage'* of Mesoscale Convective System Evolution.

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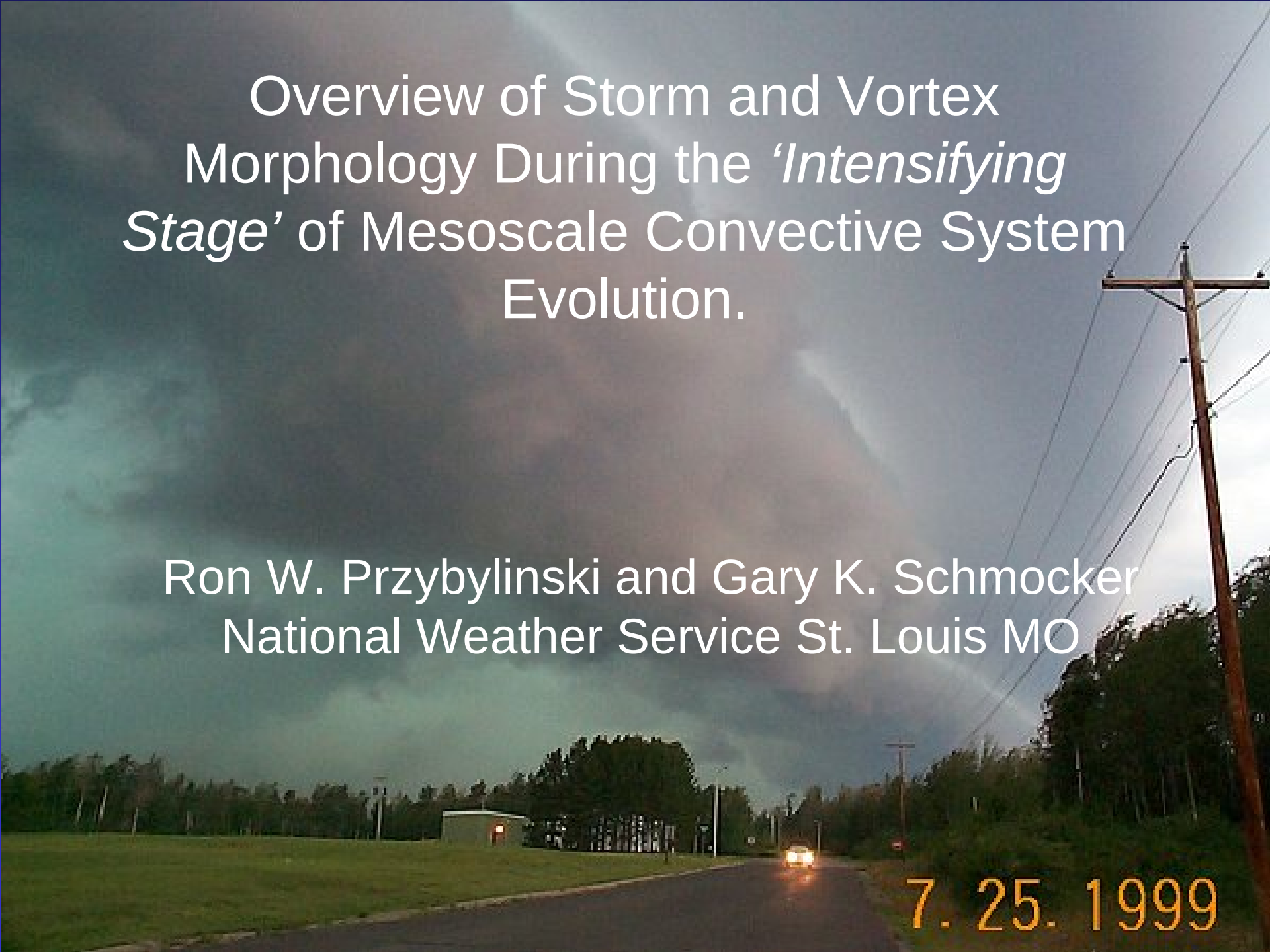


Introduction

This presentation is based on a *small sample* of WSR-88D Doppler radar observations (24 cases) collected over the Mid-Mississippi Valley Region and adjacent areas from 1992 – 2000.

The goal is to share insights into the storm - circulation evolution - during the *'Intensifying Stage' (Pre-Bow Echo – Early stages of BE)* of Mesoscale Convective Systems.

Preliminary storm conceptual models and examples of WSR-88D imagery of severe convective lines and tornadic (or non-tornadic) circulations during this stage will be shown.

We will focus on:

1. Diagnosis of the pre-convective environment (shear / (CAPE considerations).
2. the evolutionary reflectivity – Doppler velocity characteristics during the MCS's *'Intensifying Stage:* (*four preliminary storm conceptual models derived from* **21** of the **24** cases) __
3. Document location of initial damaging winds reports during this stage.
4. First approximations of how you can determine the depth of a *stable layer* north of a low-level boundary.
5. Characteristics between *tornadic* and *non-tornadic* circulations (Rotational Velocity [Vr] traces).
6. Compare these characteristics to mesocyclones associated with traditional supercells (Burgess et al. 1982; 1995)

(1) Recent Studies Utilizing Doppler Radar:

Installation of the WSR-88Ds brought a surge of studies on bow echo evolution (e.g. Funk et al. 1997; 1999); Przybylinski et al. 1997; Schmocker et al. 1998; Pence et al. 1998; Spoden et al. 1999; Wolf 2000; and others.

Regional Bow Echo studies utilizing WSR-88D data sets:

- Klimowski et al. 2000
- Przybylinski et al. 2000

Trapp and Weisman (2000) were successful in simulating non-supercell tornadogenesis with Quasi-Linear Convective Systems (QLCS).

(2) ***Data Analysis***

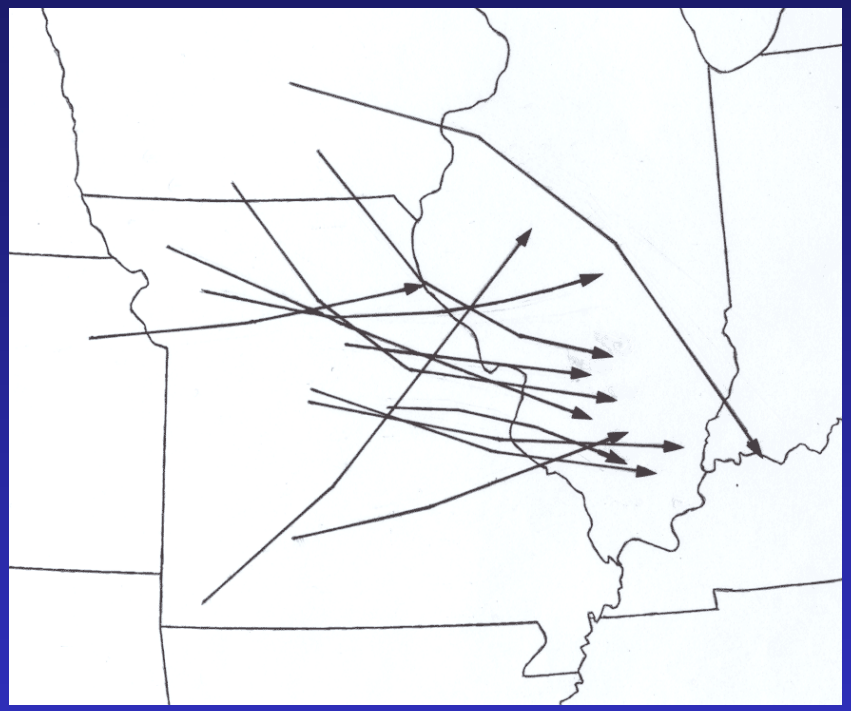
- Low-level and elevated boundaries (including fronts) were documented in many of our cases.

- Boundaries were identified by:
  - hourly surface mesoscale analyses
  - radar imagery (fine lines / lines of small convective cells)
  - visible satellite data

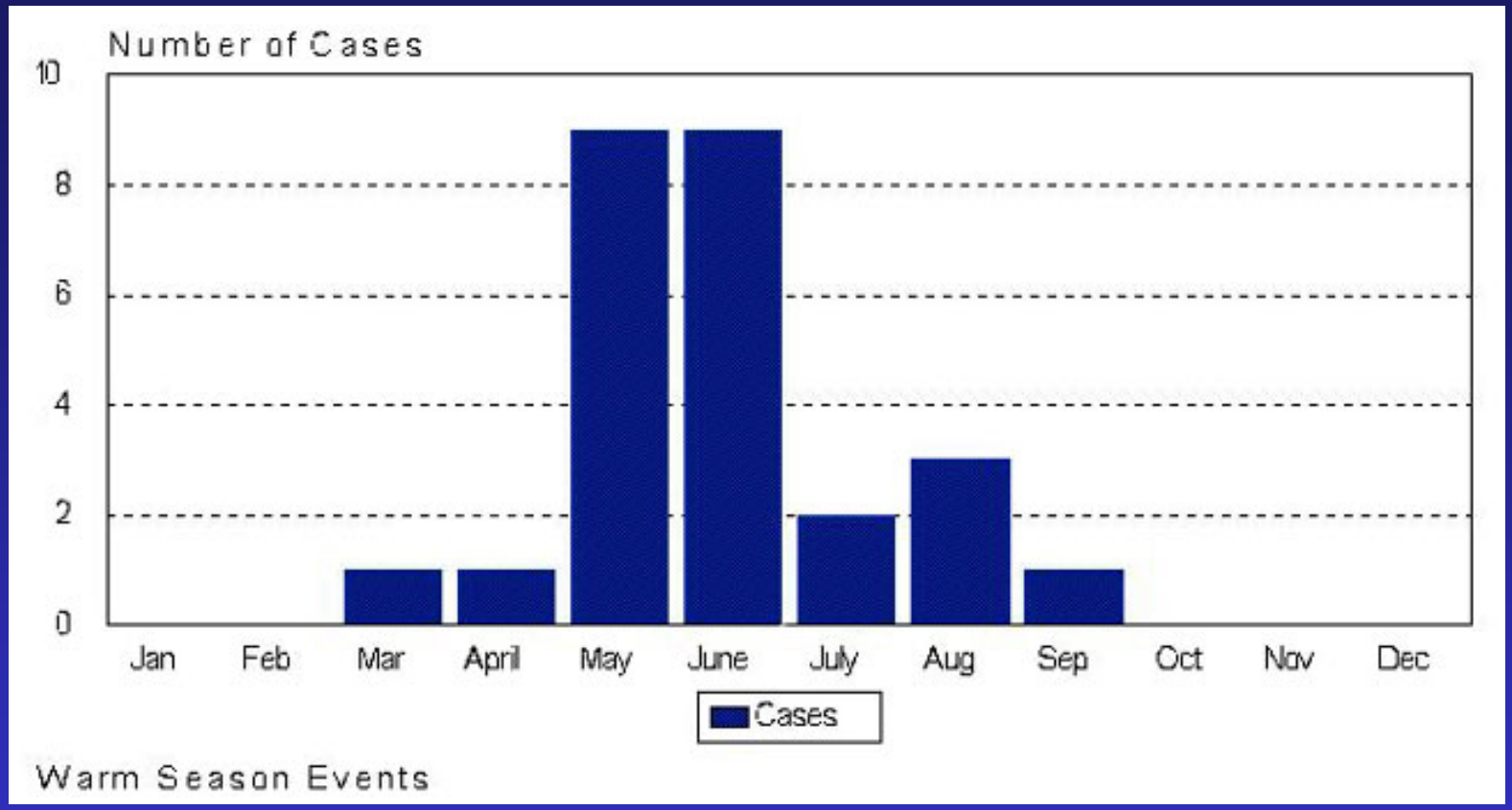
- Archive level II (90%) and Level IV data (10%) (KLSX, KEAX, KILX, KPAH) were used in our study.

- Rotational velocity (Vr) time-height traces were constructed to show mesocyclone characteristics.
- *Ground Surveys* were conducted in 18 of the 24 cases

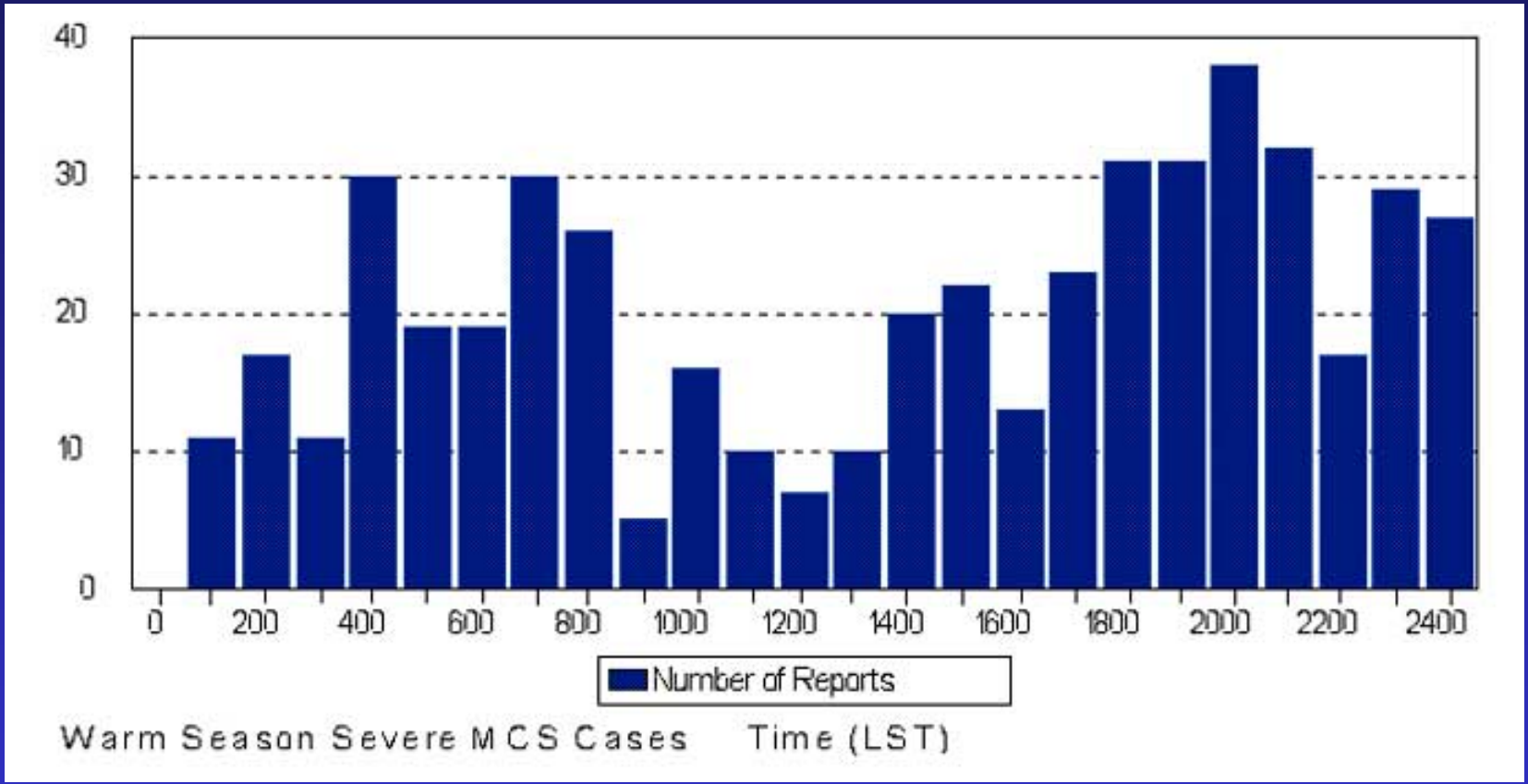
(3) *Preliminary Stratification of Data*



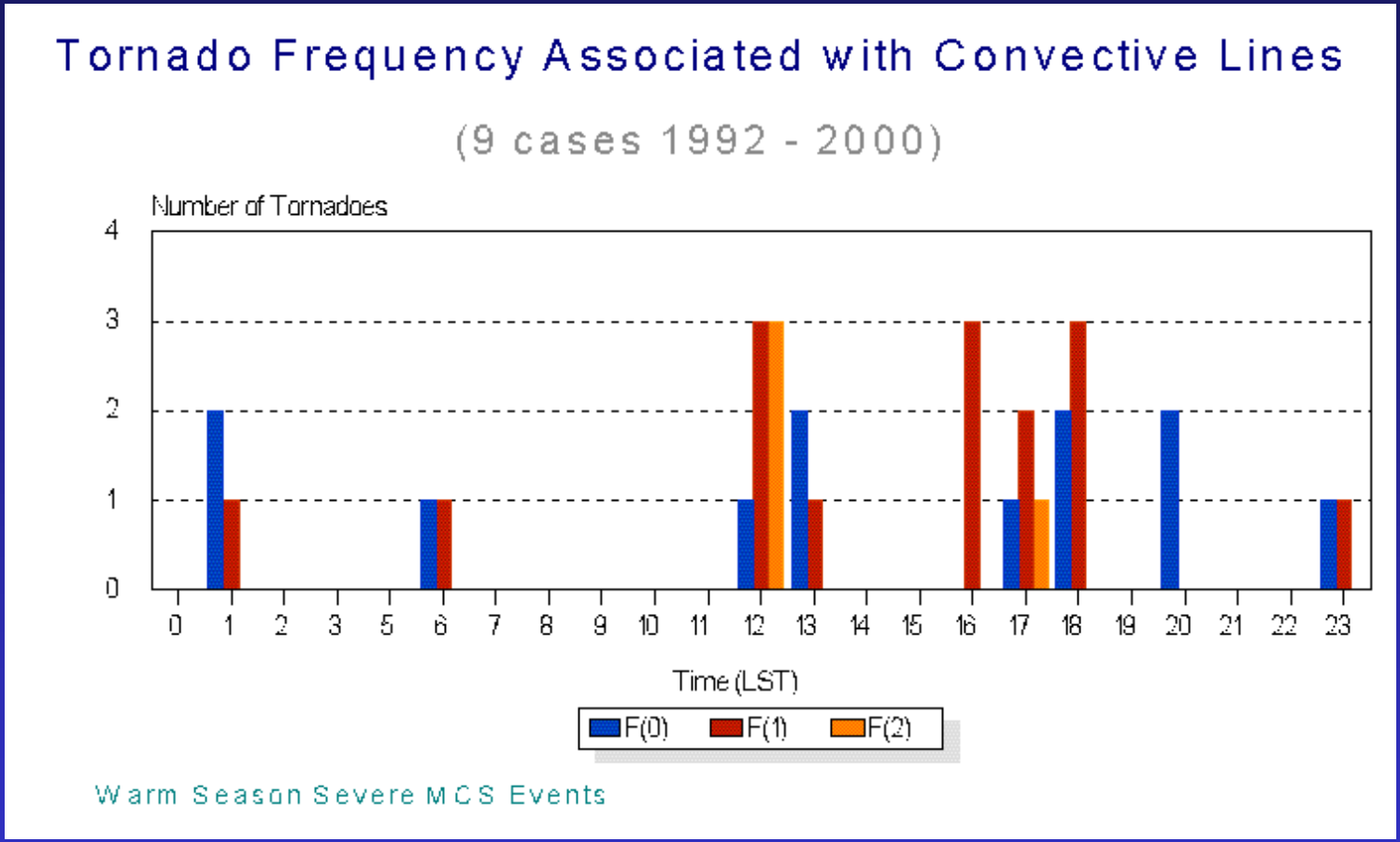
(Left Graphic) Pathways of linear to bowing MCS events (12 cases studied) for the period 1992 – 1997.
(Right Graphic) Pathways of linear to bowing MCS events studied or under study (12 cases) for the period 1998 – 2000.



Monthly distribution of MCS events (cases studied or under study) across the Mid-Mississippi Valley Region (1992 – 2000) (Note – most of the events during the month of May occurred after May 15).



Mid-Mississippi Valley Severe Wind Frequency (time of wind damage reports for 21 cases (1992 – 2000)



Mid-Mississippi Valley Tornado Frequency for squall lines (cases studied) 1992 - 2000. Tornadoes occurred with 9 MCS events. (Working with a small sample)

4. *Squall Line Studies* (Early work)

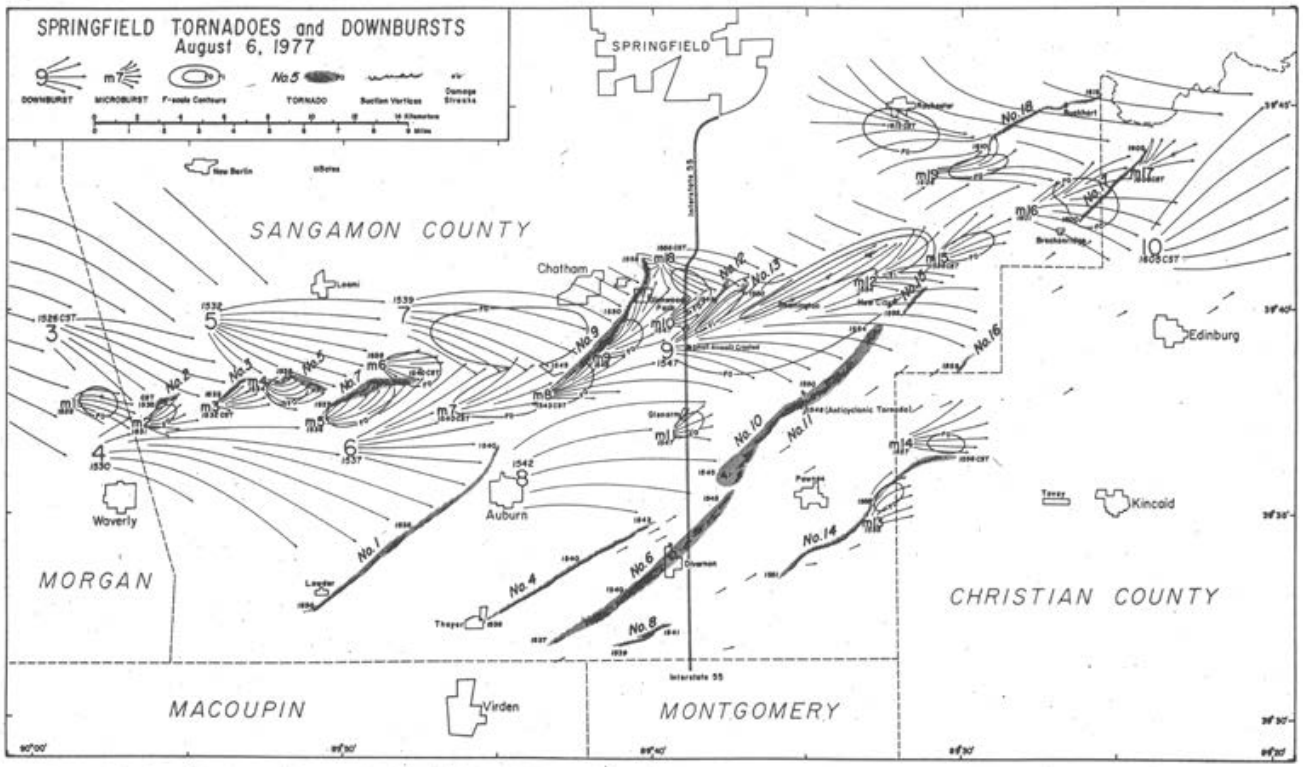
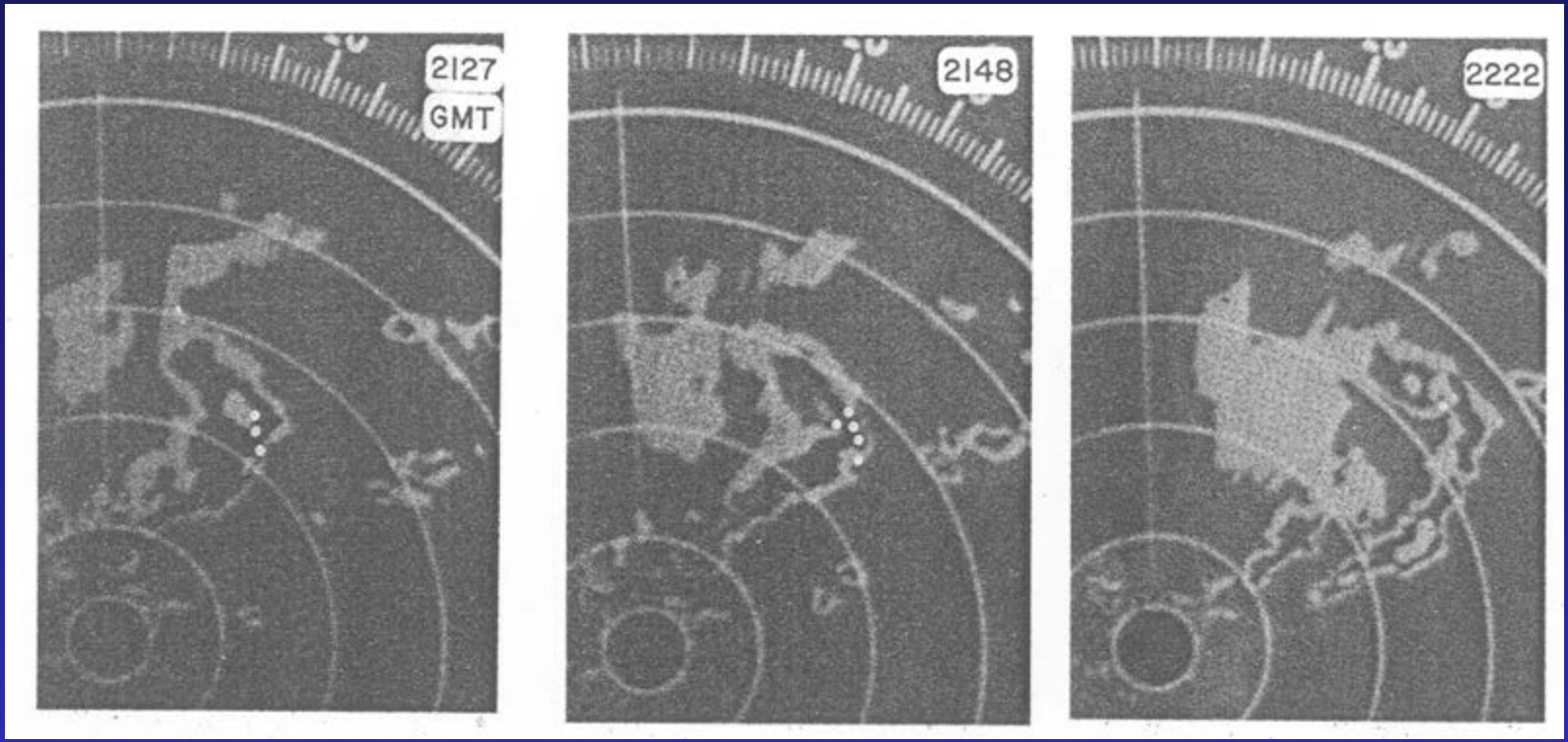


FIG. 1. Mapping of the damage from tornadoes (identified by "No."), downbursts (identified by large numeral), and microbursts (identified by "m") on 6 August 1977. "Streamlines" of damage and F-scale contours are mapped. See figure legend for additional symbol explanation.

FORBES AND WAKIMOTO 1983

Forbes and Wakimoto (1983) conducted a detailed analysis of the 6 August 1977 bow echo event across central Illinois. Numerous downbursts (microbursts) and 18 tornadoes were recorded with this event. (17 were cyclonic / 1 anticyclonic).



WSR-57 Radar Data from KSTL on 6 August 1977. The white dots represent locations of downburst (and tornadoes). Time is in UTC. (From Forbes and Wakimoto 1983).

Squall Line Studies (recent work)

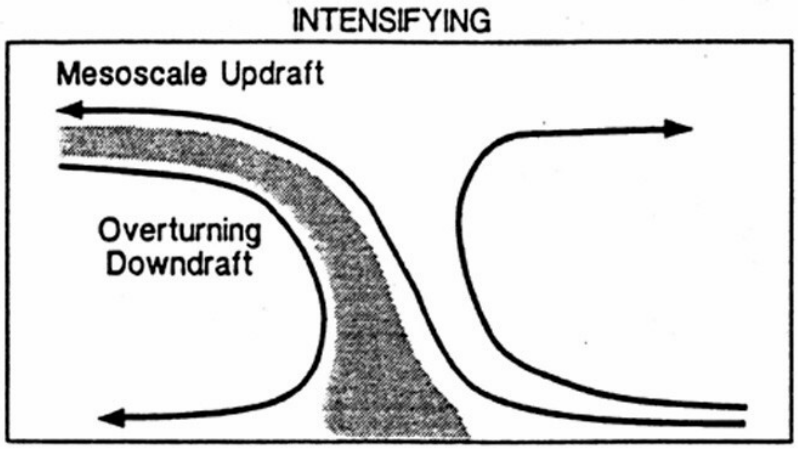
- Utilizing a special Doppler data set from Australia, Rasmussen and Rutledge (1993) showed that an MCS evolved through four stages:
  - **Formative**
  - **Intensifying**
  - **Mature**
  - **Dissipating**

- They described MCS evolution as a ***' continuum of changes'*** of the kinematic and reflectivity structures characterized by a gradual tilting of the flow branches and reduction of updraft strength and echo intensity.

-**RR** defines the ***'Intensifying Stage'*** when the convective line evolves into a *nearly solid line echo.*
  - *cell towers reach their greatest height*
  - *updraft intensity is strongest*

- Early stages of the flow branches.
  - **Front to Rear Flow**
  - **Mesoscale Rear Inflow**

- Shaded region between these two branches is defined as a ***'sloping zone of negative horizontal vorticity'***



Schematic diagram of the 'Intensifying Stage' of squall line flow features adapted from Thorpe et al. (1982). Vorticity zone is shaded region.

- Negative horizontal vorticity results from **strong horizontal gradients of buoyancy:**
  - ***positive buoyancy*** due to heating of condensation / freezing along the leading edge.
  - ***negative buoyancy*** due to cooling of evaporation, melting, and condensate loading (convective towers).

- Preliminary findings from our COMET study showed that the leading edge of this zone of *'negative horizontal vorticity'* is a preferred region for vortex generation.

- *Convective-scale vorticies* (tornadic and / or non-tornadic may form along the leading edge of this zone (release of a horizontal shearing instability along the leading edge of the convective system)

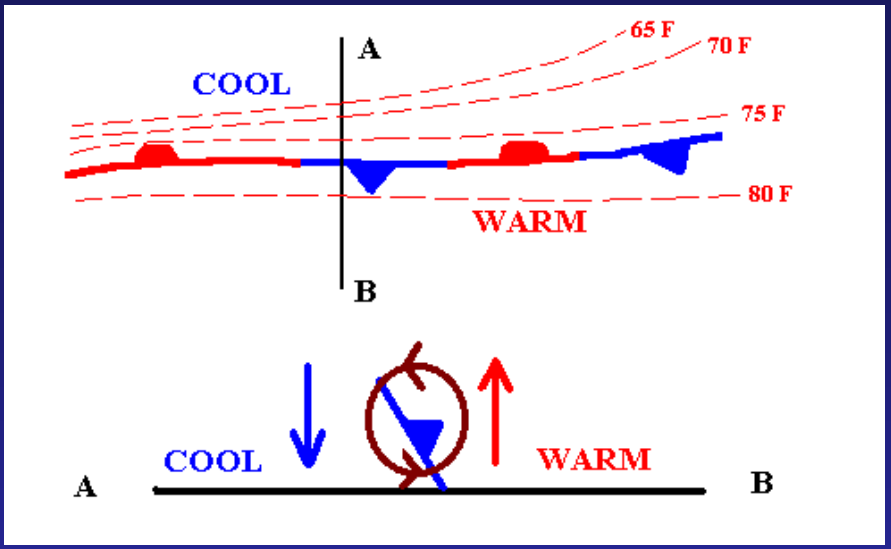
Low-level Boundaries

- Second important preliminary finding from several of our cases was the presence of:
    - a ***low-level boundary*** from earlier convection or
    - an ***old quasi-stationary frontal boundary***

- Either of these features were frequently oriented ***orthogonal*** to the approaching convective line.

- **16** of the **21** MCSs we studied appeared to be directly influenced by either a low-level or elevated boundary**.**

How important are boundaries?
Very important

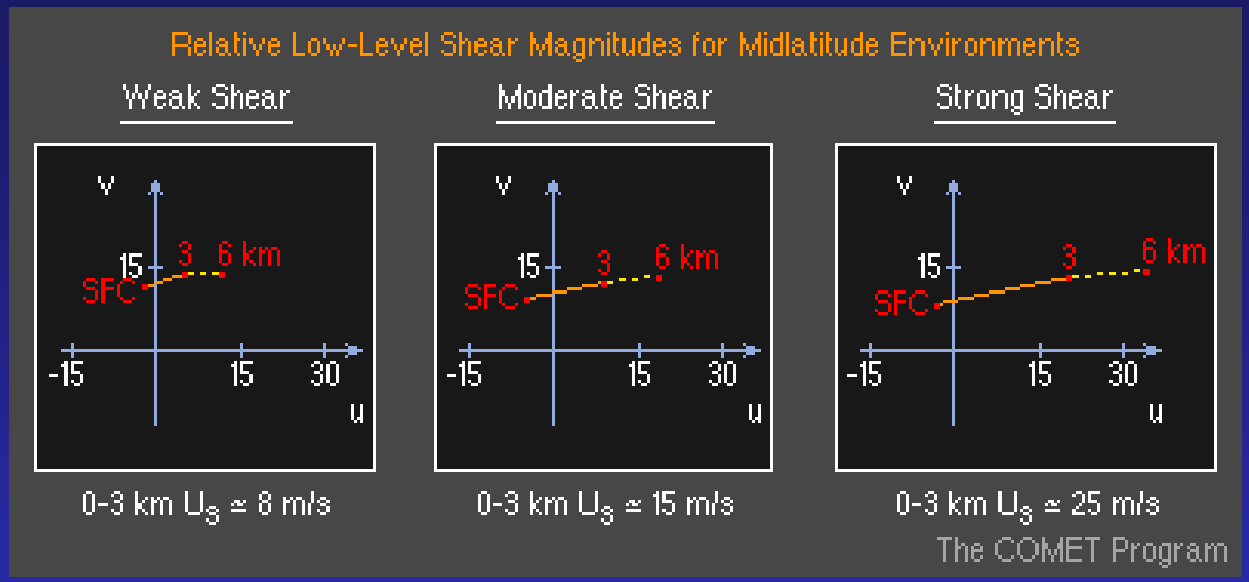


- **Boundaries** serve in two ways:

1) local forcing mechanism for convective initiation
2) as a source of local vorticity augmentation for convective-scale vortices.

- From the ***Vortex Project*** Markowski et al. 1998 and Rasmussen et al. 1994 showed that nearly ***70% of all tornadoes*** observed in **VORTEX** were associated with boundaries.

5. *Pre-Convective Environment*



Period	Mean CAPE	Bulk Shear (0-3 km)
1992 – 1997 (13 cases)	3400 J/Kg	14.3 m s^{-1}
1998 – 2000 (8 cases)	3572 J/Kg	13.8 m s^{-1}

Pre-Convective Environment

ALL CASES	CAPE J/kg (Mean)	BULK SHEAR (Mean 0 –3 km)
Weak Shear (5 cases)	3592 J/kg	9.6 m s^{-1}
Moderate Shear (11 cases)	3367 J/kg	16.8 m s^{-1}
Strong Shear (5 cases)	3147 J/kg	21.2 m s^{-1}

- Sample size still too small.

(6) *Storm Conceptual Models*

- **Four Groups** of storm morphologies were derived from our preliminary data set. A fifth group, classifed as 'other' was needed for 3 cases.

Four storm conceptual models included:

1) Low-level boundary intersecting the northern part of the convective line (7 cases).

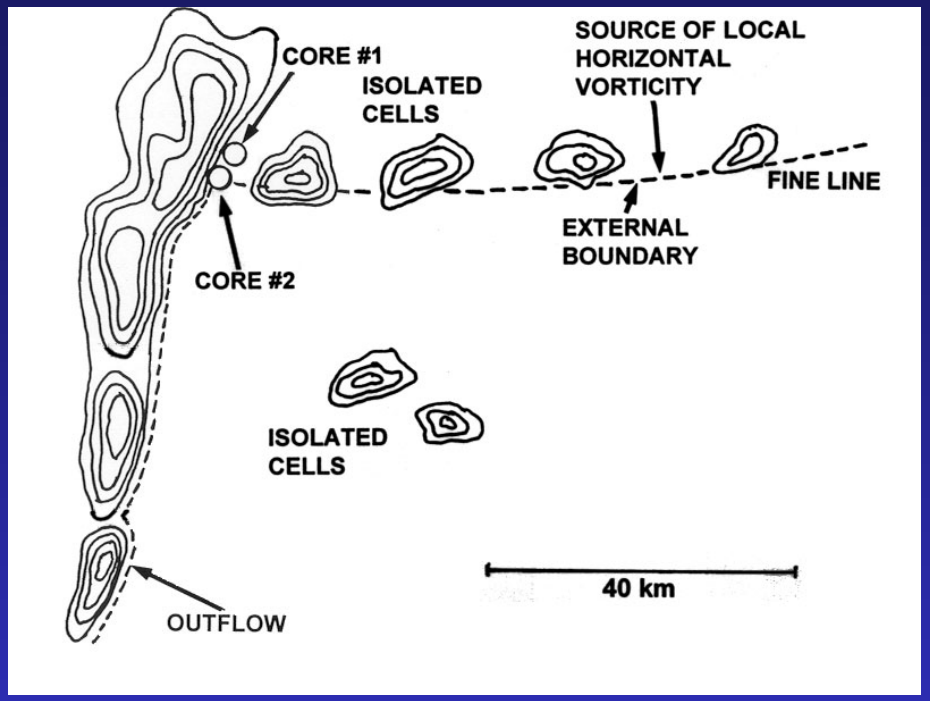
2) Low-level boundary or frontal boundary intersecting the southern part of the convective line (7 cases).

3) East-west frontal boundary located 30 to as much as 150 km south / southwest of the MCS (5 cases)

4) Low-level boundary intersecting the updraft region of a High-Precipitation (HP) supercell (2 cases).

1. Low-level boundary intersecting the northern end of a convective line.

- 7 cases
- 6 events late afternoon or early evening.
  1 event mid morning.



a) Reflectivity Characteristics:
Line of small isolated cells or reflectivity fine line intersects and extends downwind from the northern end of the larger linear convective line (pre-bowing).

- east-west line of isolated cells reflect location of low-level boundary.
- First reports of damaging winds occurred:
  - ***south of the intersection in all seven cases.***

b) Group 1: *Circulation Trends:*

-In all 7 cases, first two circulations formed in the vicinity of the low-level boundary – convective line intersection.

- In 3 of the 7 events, *numerous circulations (4 cores or more)* were identified along the cyclonic shear side of the bow (northern end to near the apex).
- Core 3 and subsequent cores occurred as much as 10 to 15 minutes after initial identification of Core #2.
- Non-supercell tornadoes (F0 – F1) occurred in each of these 3 events, with Cores 2 and 3; and with Core 4 in one of the three cases.
- Two events – *moderate shear* / high CAPE; third event *weak shear /* high CAPE.

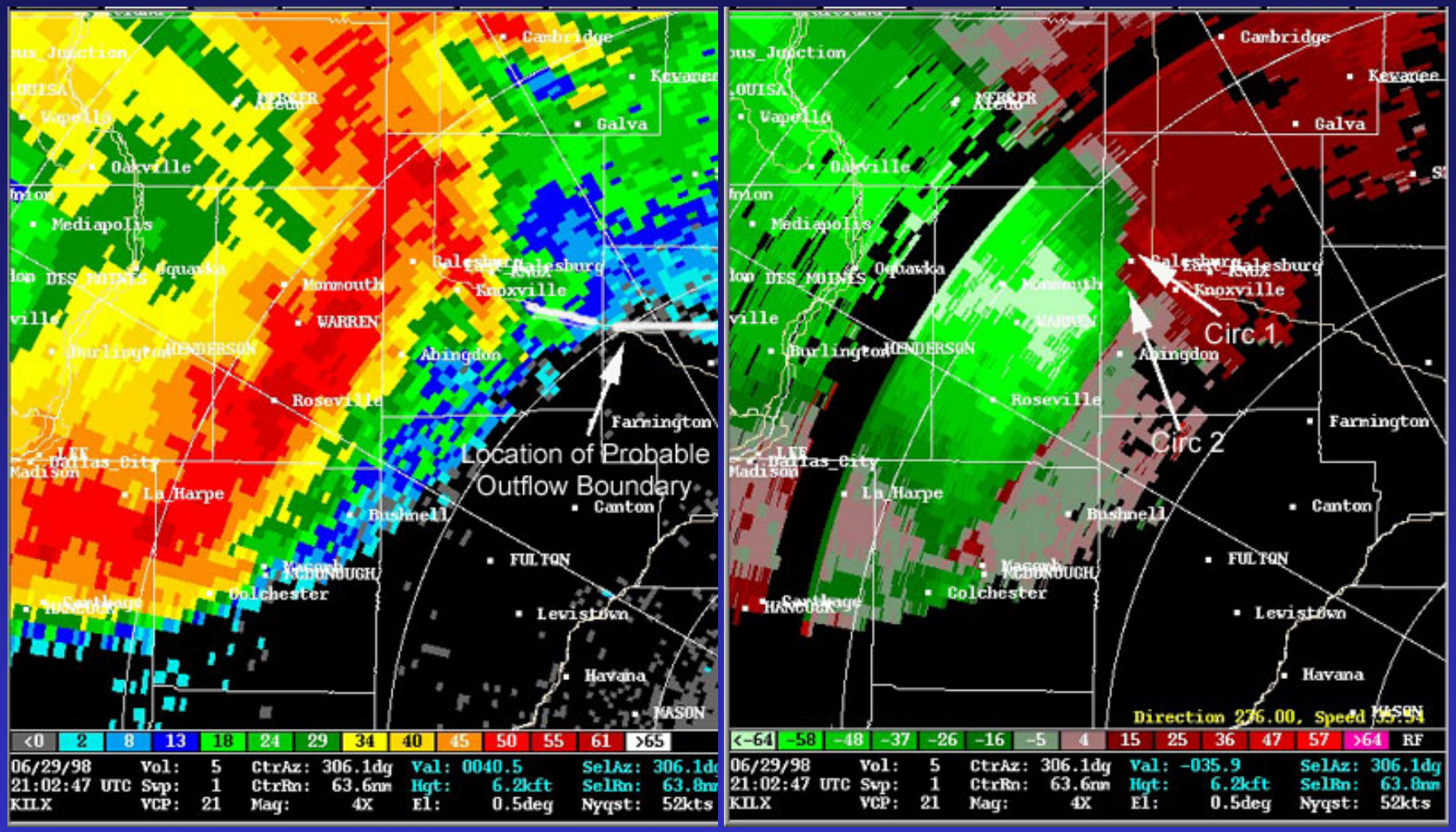
- In the remaining 4 cases; 2 or 3 mesocyclone cores were documented. None which spawned tornadoes.

b) Group 1: *Circulation Trends cont'*

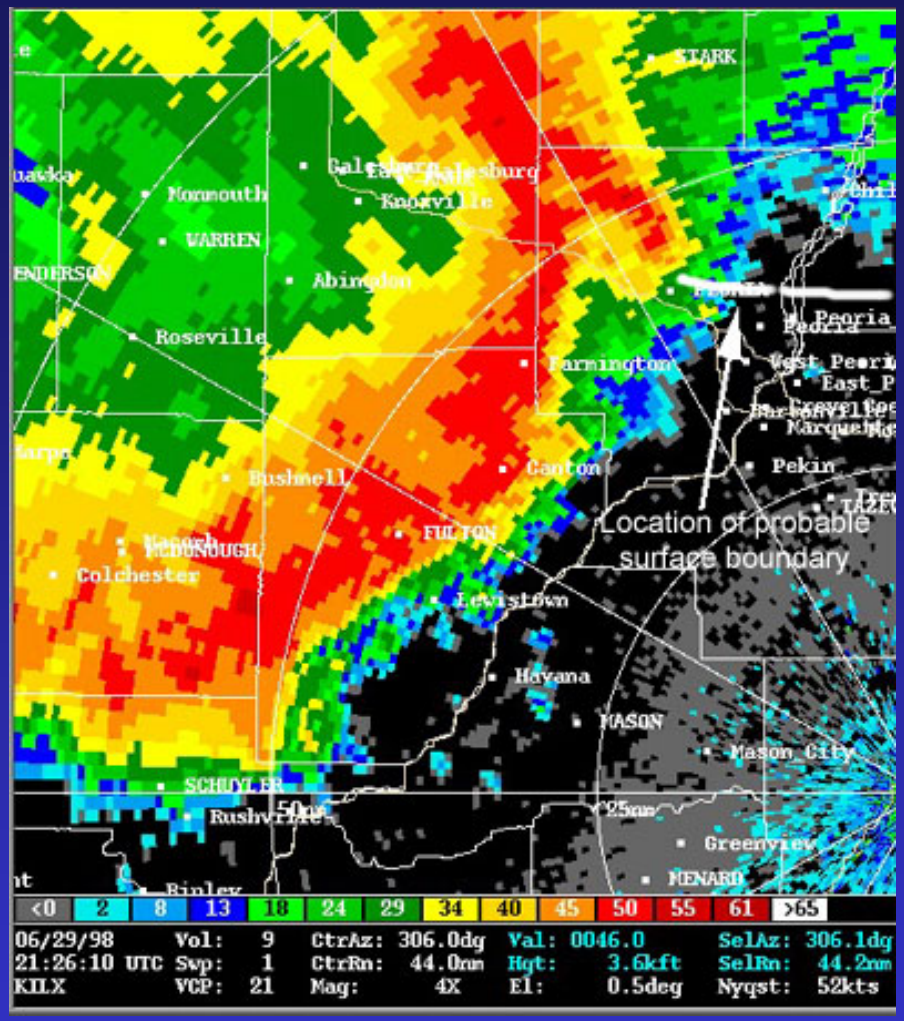
Circulation characteristics:

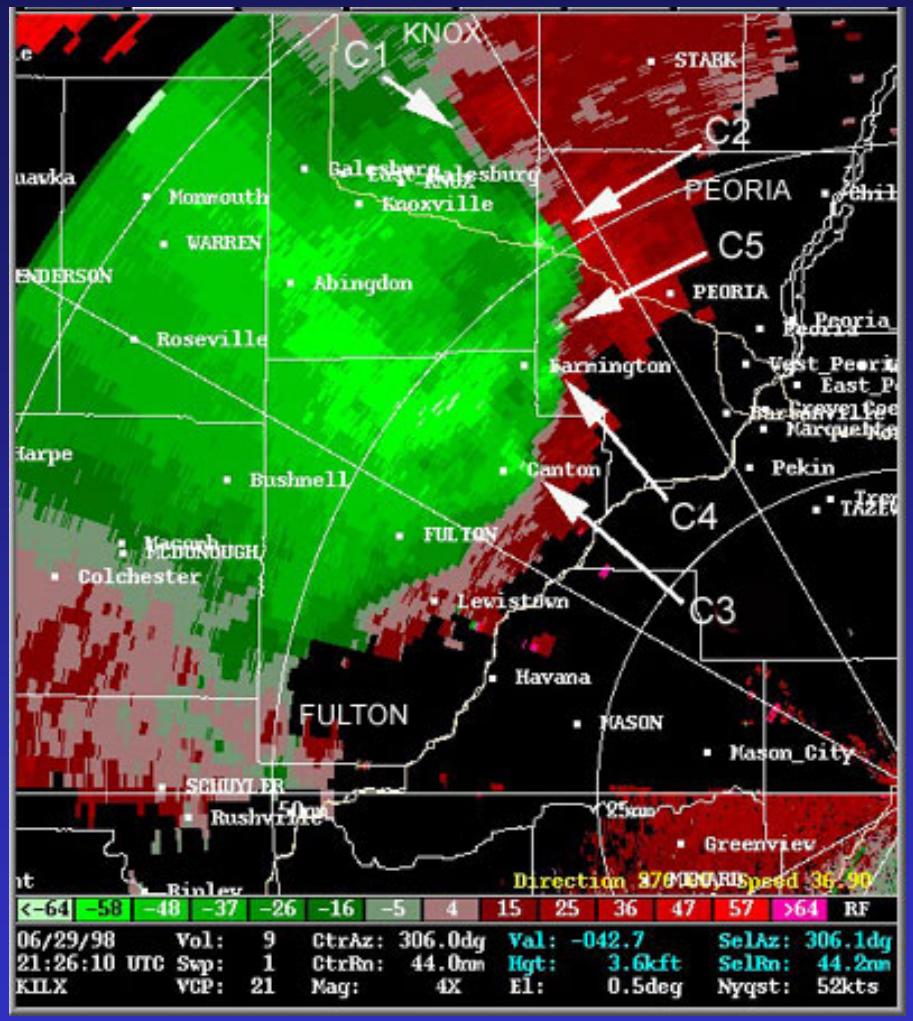
- In 5 of the 7 events, first two cores formed in the vicinity of an isolated cell (*anchored to a boundary)* – convective line merger (preferred region of enhanced convergence – vertical stretching of the updraft).
- Remaining two cases – first two cores formed near an external boundary (fine line) – convective line intersection *(but no cell-line merger).*

- Core #1 – weaker Vr magnitudes / shallower depths compared to Core #2.
- Core #2 – stronger Vr magnitudes, greater depth, upscale growth (*non-descending)* and longest lifetimes.
- Core #3 and subsequent cores – *non-descending characteristics,* similar Vr magnitudes, nearly equal depth, however often shorter lifespan compared to Core #2.

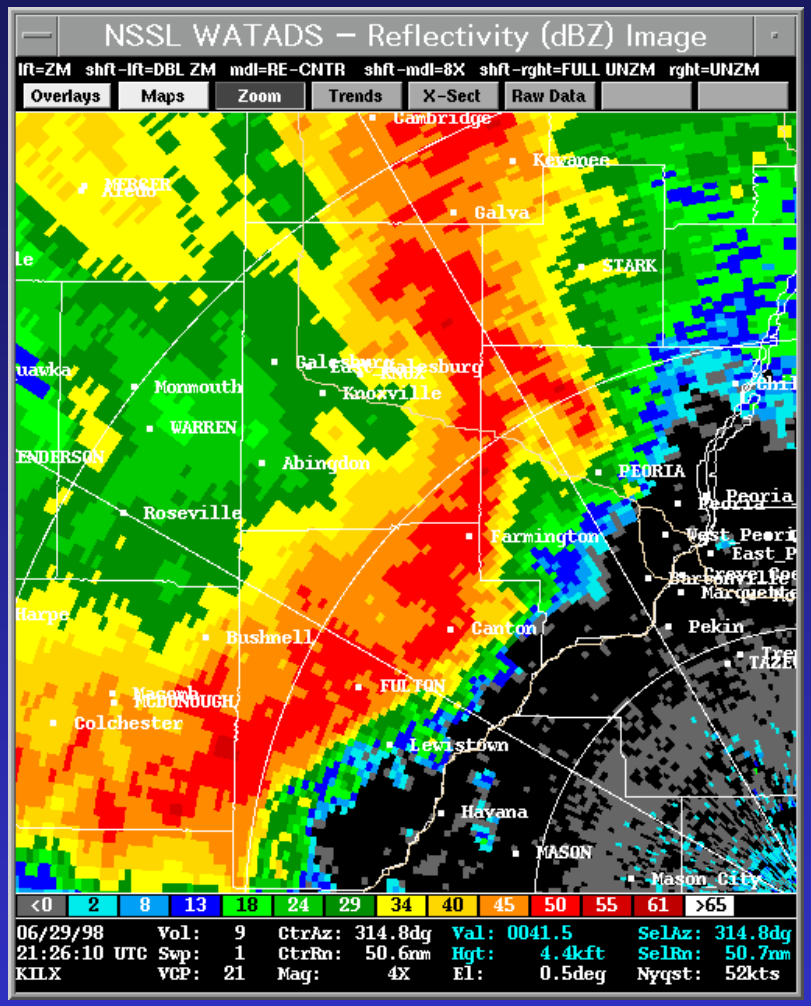


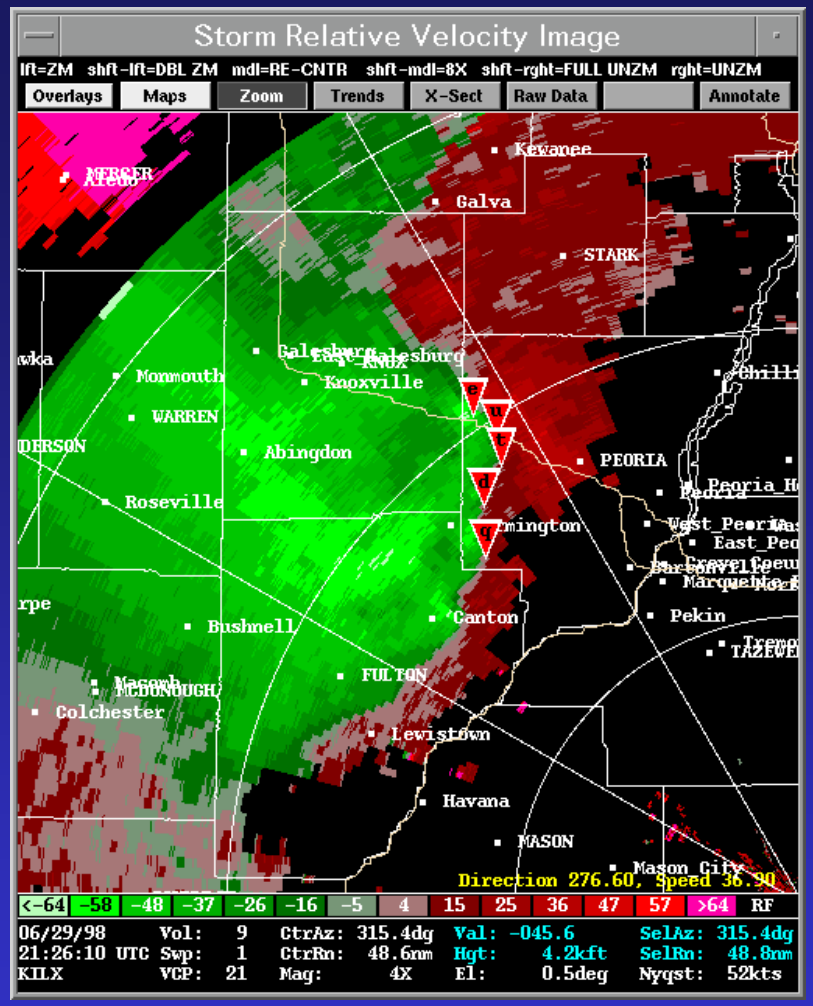
2103 UTC 29 June 1998 reflectivity (0.5°)(left); storm-relative velocity (right) from Lincoln IL (KILX). Convective towers extending southeast from the northern end of the large line reflects the location of an old outflow boundary. Circulation cores #1 and #2 formed at this intersection.





2126 UTC 29 June 1998 reflectivity (0.5°) slice (left); storm-relative velocity (right). Circ #2 intensified rapidly since 2103 UTC and became tornadic (F1 damage). Core #3 became tornadic only during the very early stages of its lifetime. Core #4 became tornadic after 2135 UTC.





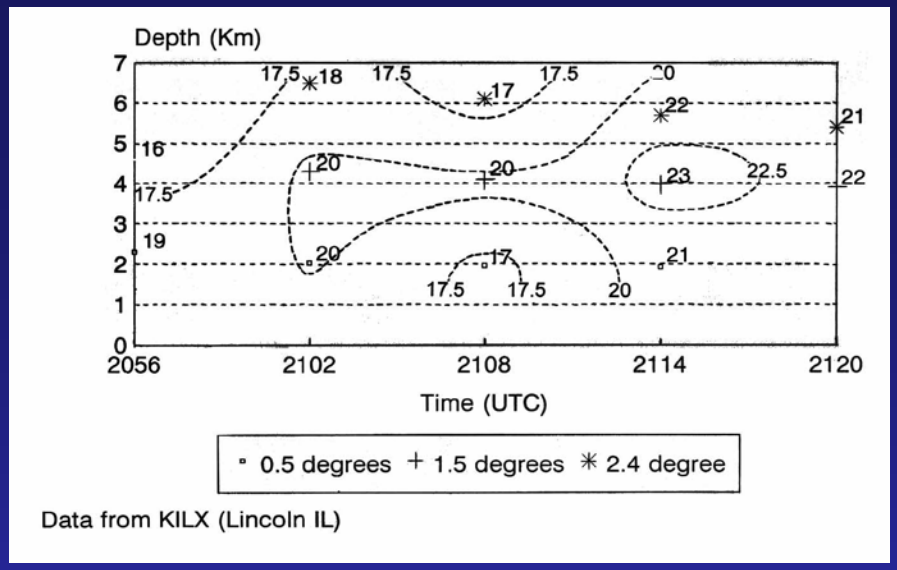
2126 UTC 29 June 1998 reflectivity (0.5° slice)(left); storm-relative velocity with TVSs (TDA) output (right).

Comparison between Mesocyclone Cores 1, 2, and 3

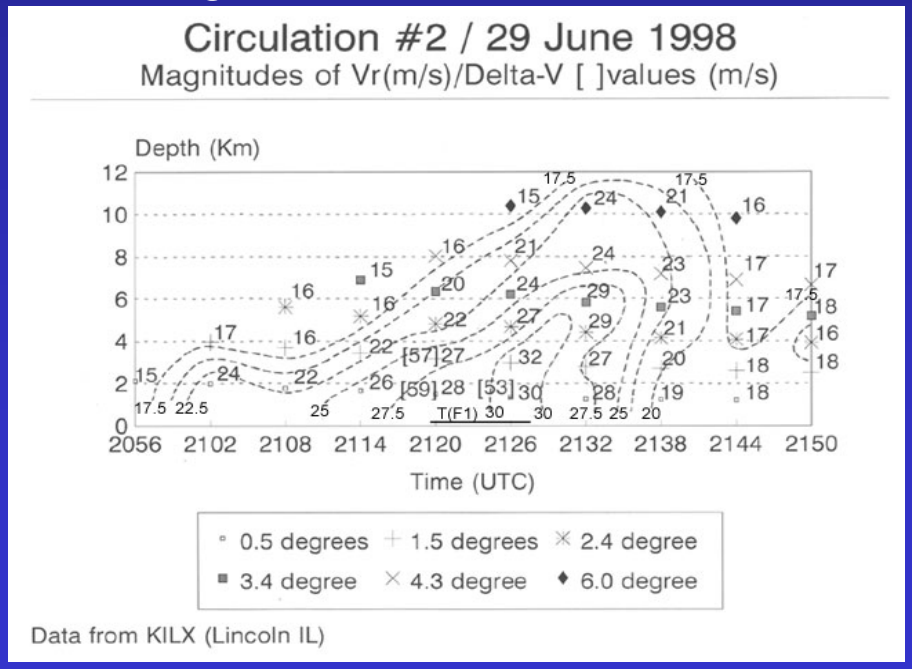
Core #1 – weaker rotation / lower overall depth compared to Core #2.

Core #2 – upscale growth (non-descending characteristics) with strongest rotation detected within lowest 3 km.

- Tornado produced **F1** damage between 2120 and 2126 UTC just before Core #2 reached its greatest depth.



Time-height Vr trace Core #1.



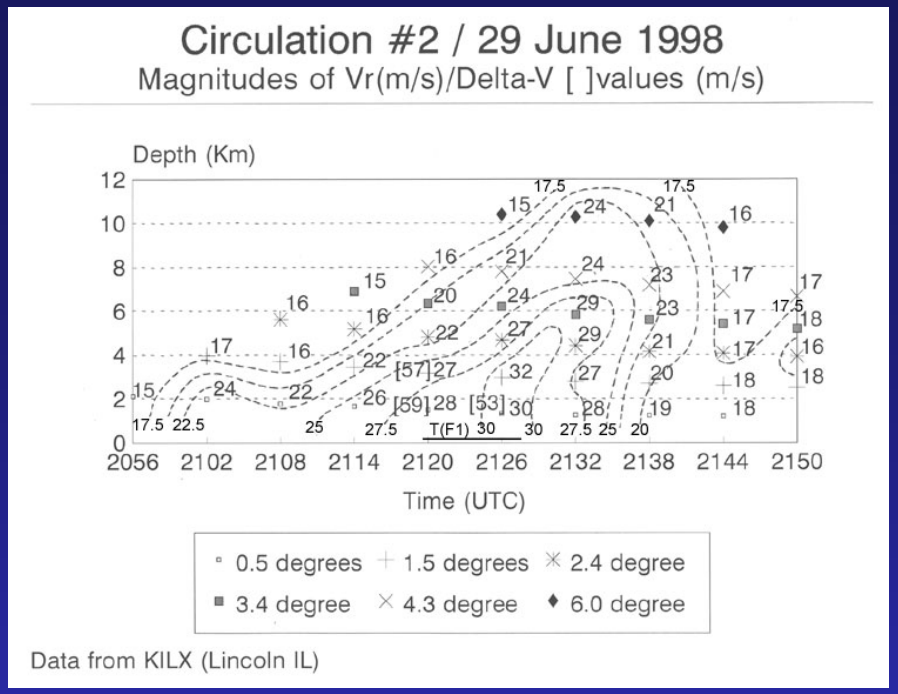
Time-height Vr trace Core #2.

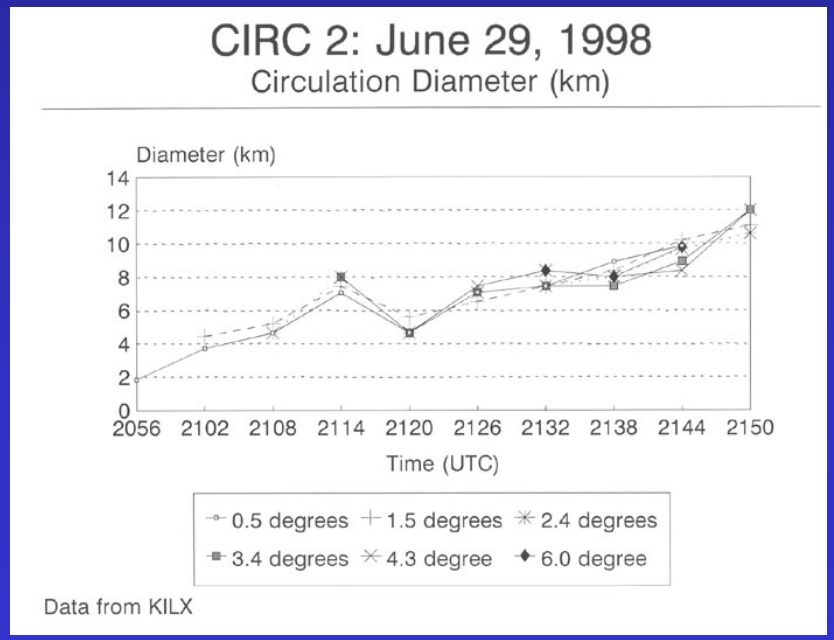
Core #2

- Showed *'non-descending'* characteristics with the strongest rotation detected within the lowest 3 km.

- Tornadogenesis occurred just before Core 2 reached its greatest height and during the period of strongest low-level rotation.

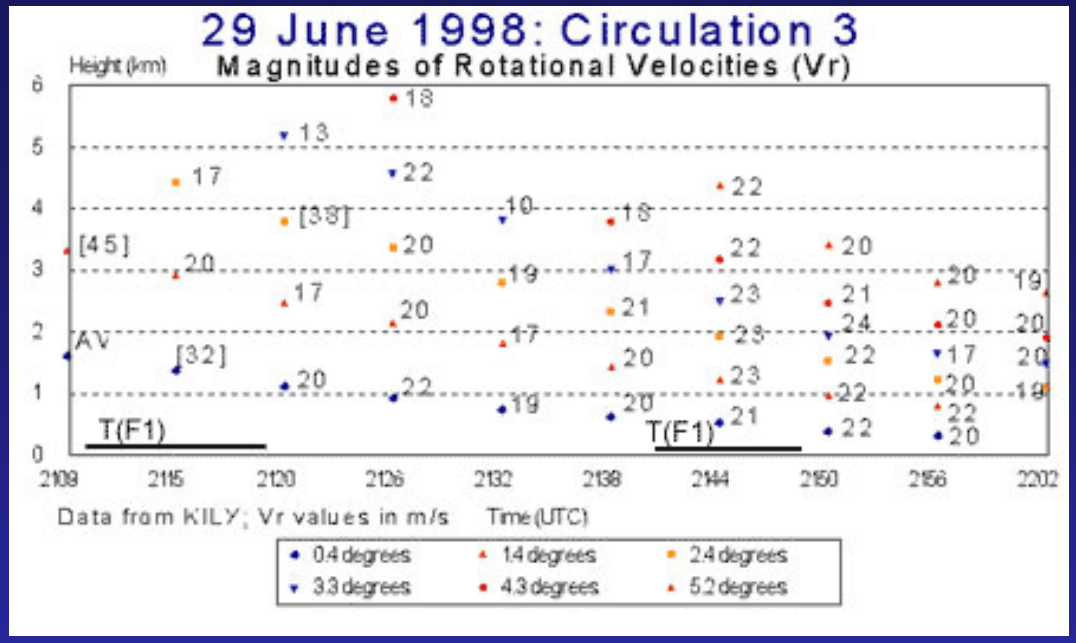
- On Circulation diameter trace note the drop in core diameter between 2114 and 2120 UTC – just before tornado-genesis.

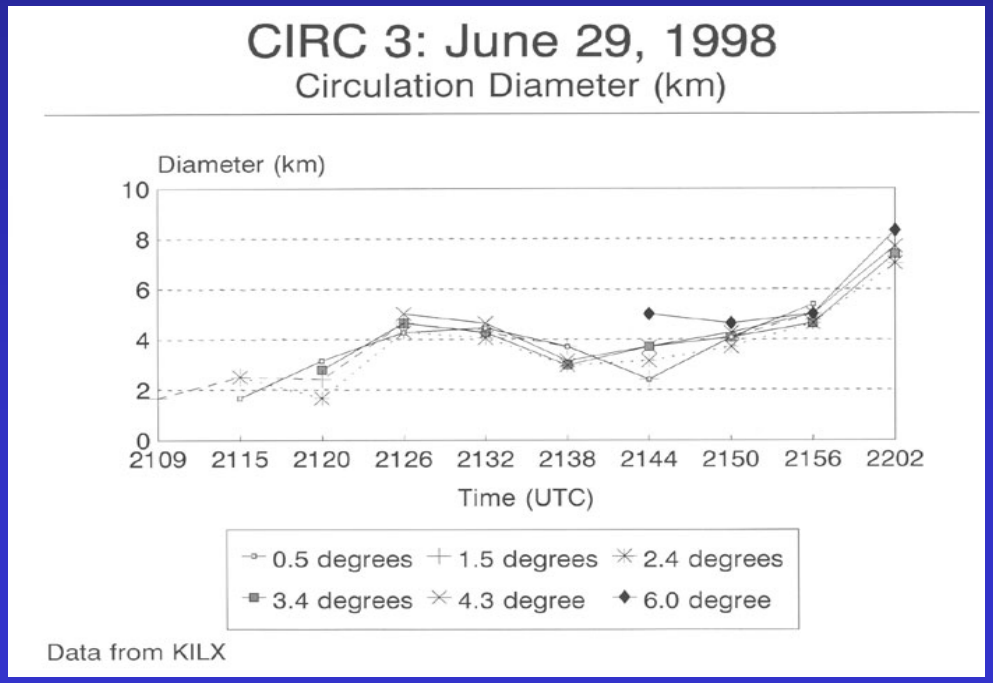




Core #3:

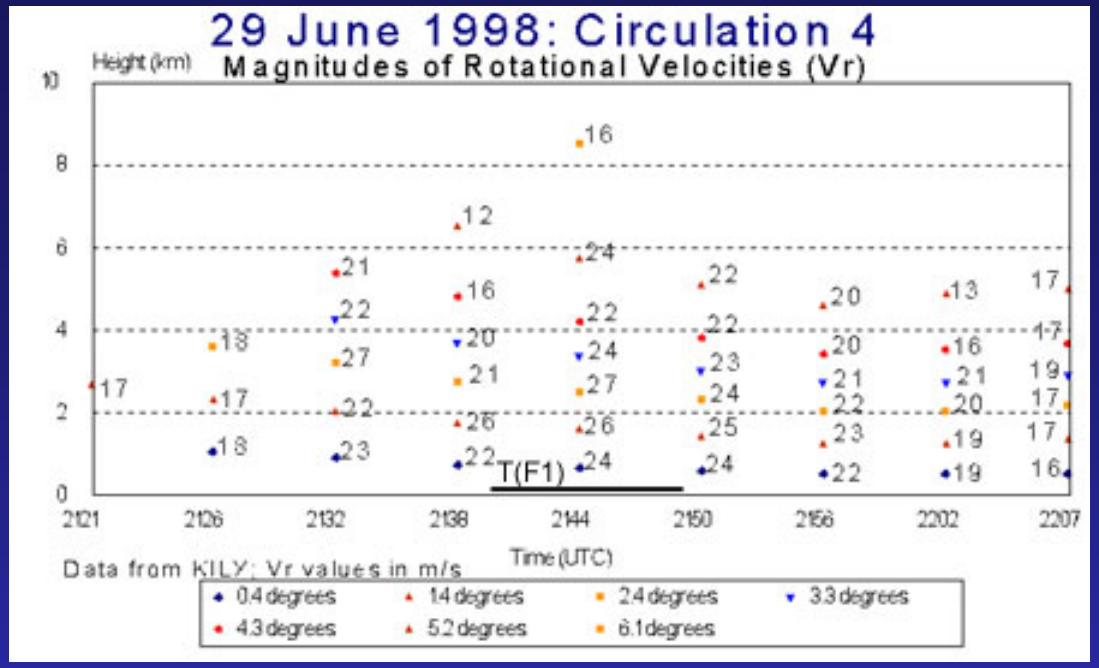
- Showed rapid *'non-descending'* characteristics during the early stages of the circulation's lifespan.
- Strong gate-to-gate shears [Delta V] were detected during the first two volume scans.
- Non-supercell tornado occurred between 2109 – 2120 UTC.
- Second peak (vortex stretching) occurred at 2144 UTC – and a second tornado occurred.

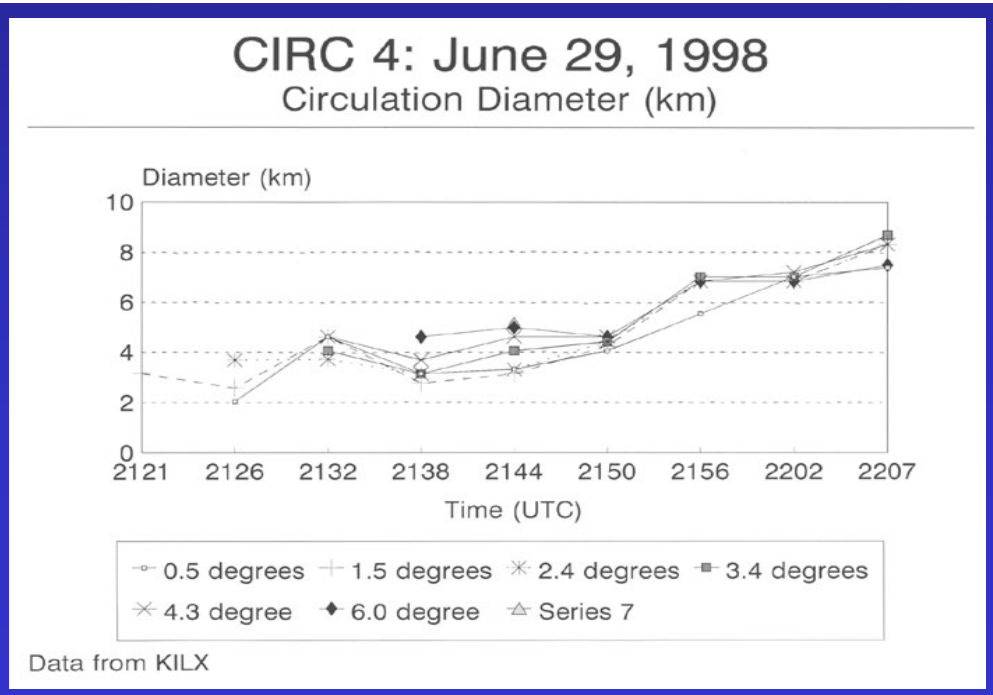


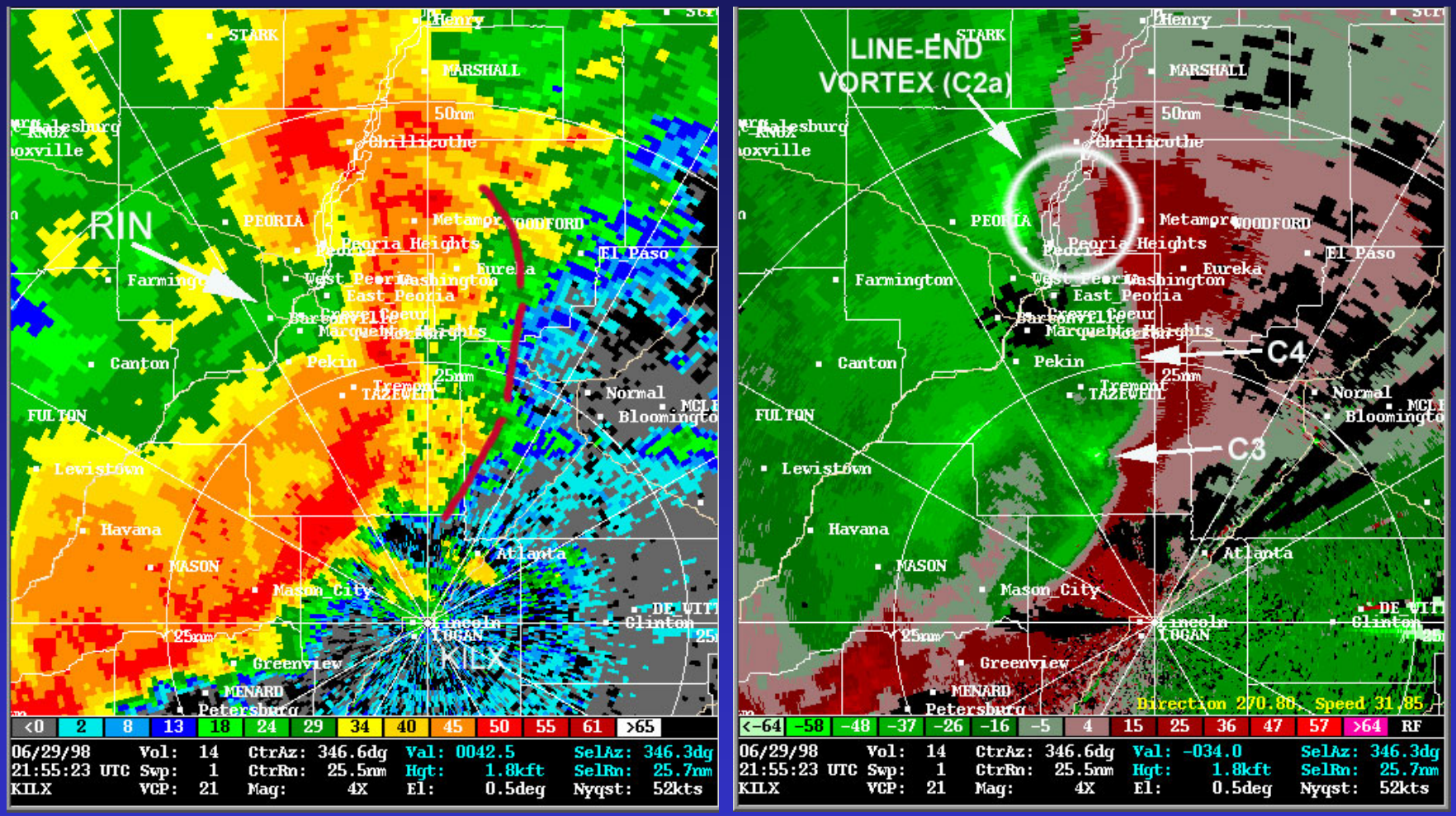


Core #4

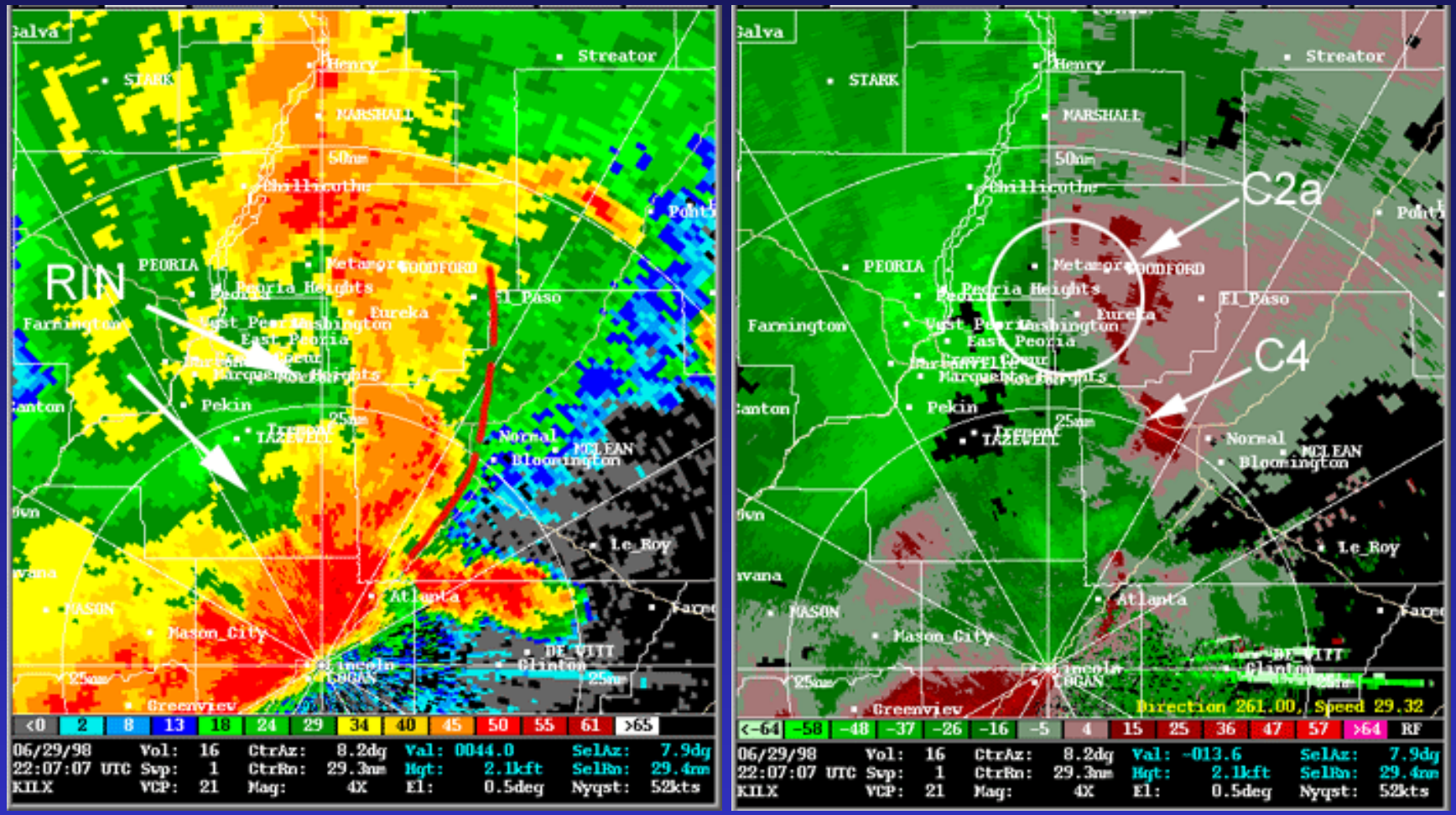
- showed similar circulation trends to Circ #2.
- *Non-descending characteristics* with the strongest rotation detected within the lowest 3 km.
- Tornadogenesis occurred just preceding the core reaching its greatest height and strongest rotation within the lowest 3 km.



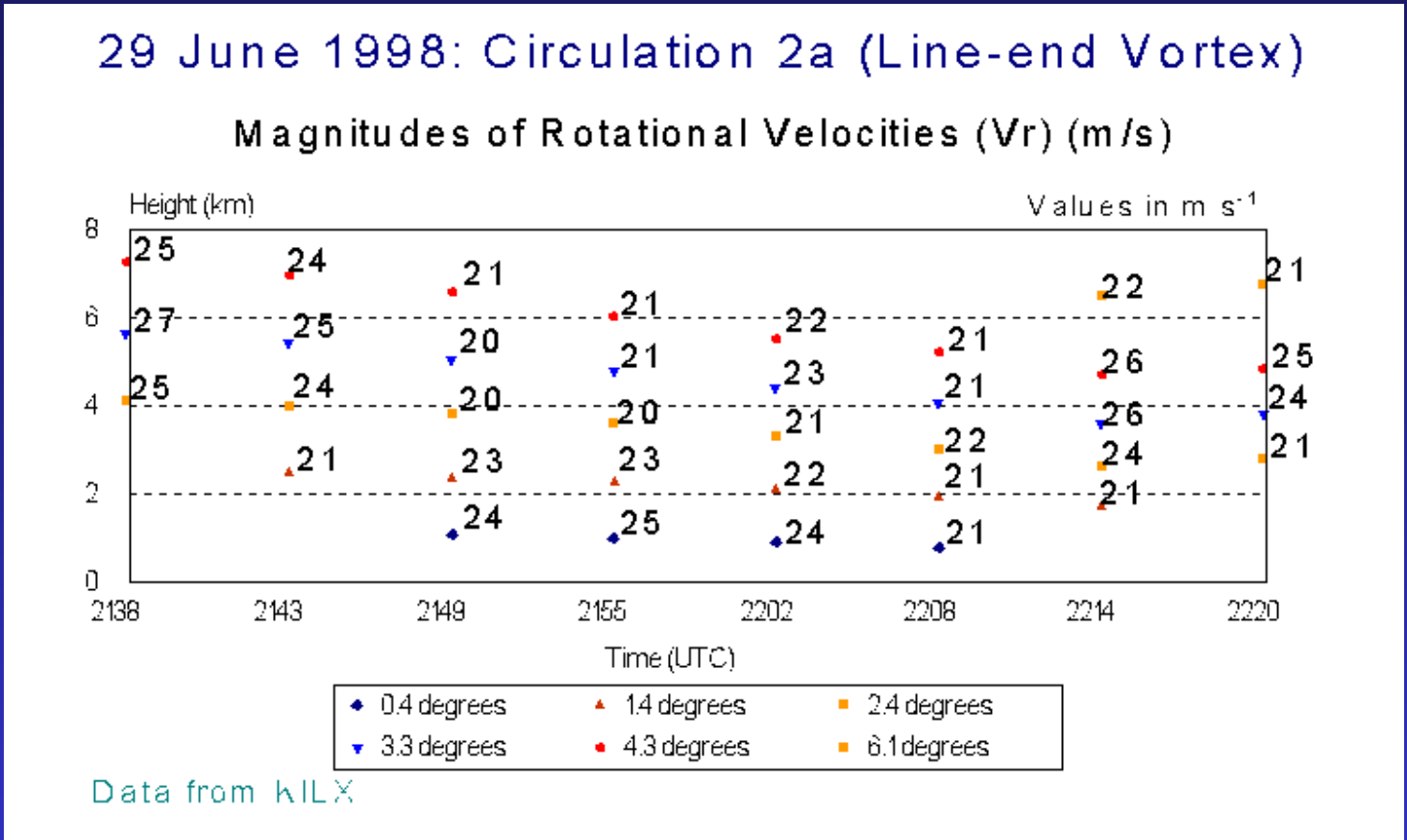




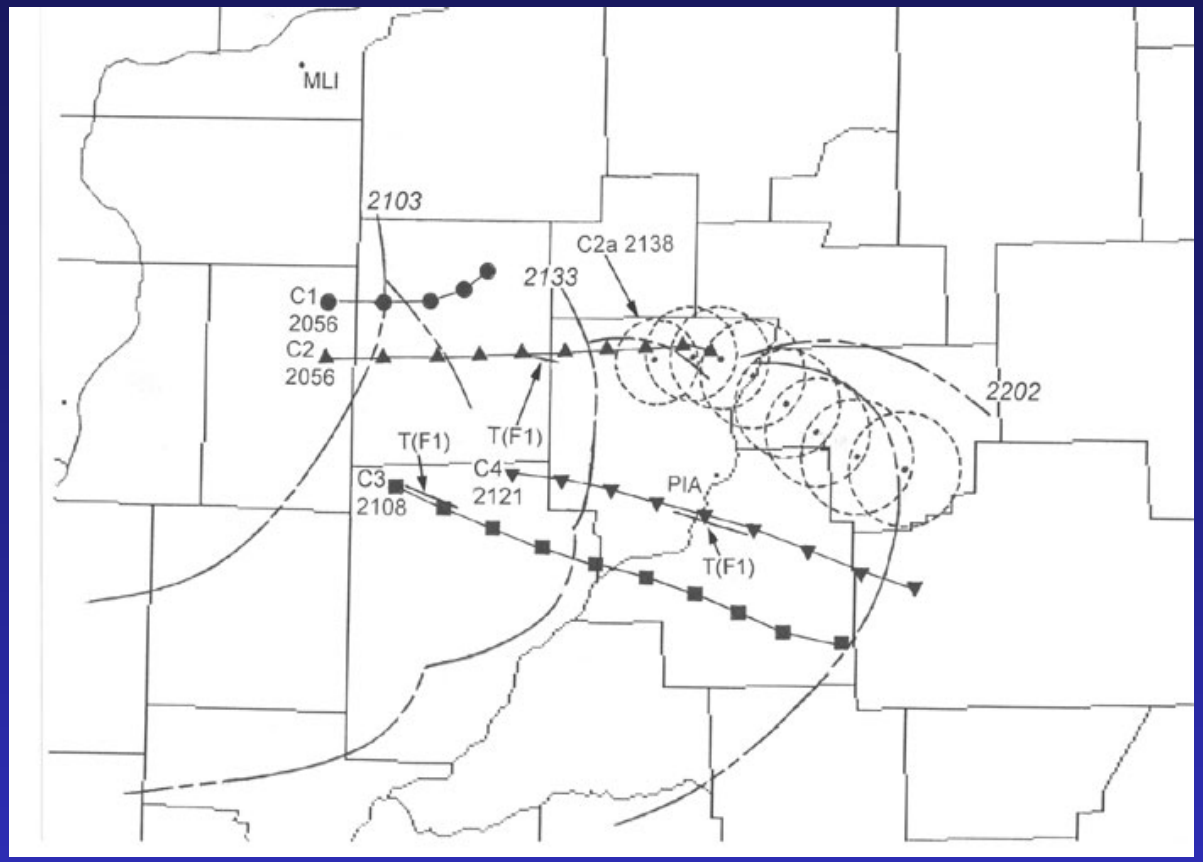
2155 UTC 29 June 1998 reflectivity (0.5° slice) (left); storm-relative velocity (right). Large-scale circulation (C2a) associated with comma-head echo is referred to as a **'Line-end Vortex.'** Most extensive wind damage occurred along and south of this circulation's path (Leading Edge -Dashed Red Line).



2207 UTC 29 June 1998 reflectivity (left) / SRM velocity (right) (0.5° slice) from KILX. Line-end vortex C2a broadens and becomes an unbalanced vortex. Note the weakness in the reflectivity field along the southern periphery of the line-end vortex (west of the red dashed line). These convective cells do not mature compared to the cells further southwest along the line due to the system cold pool overwhelming the ambient shear.

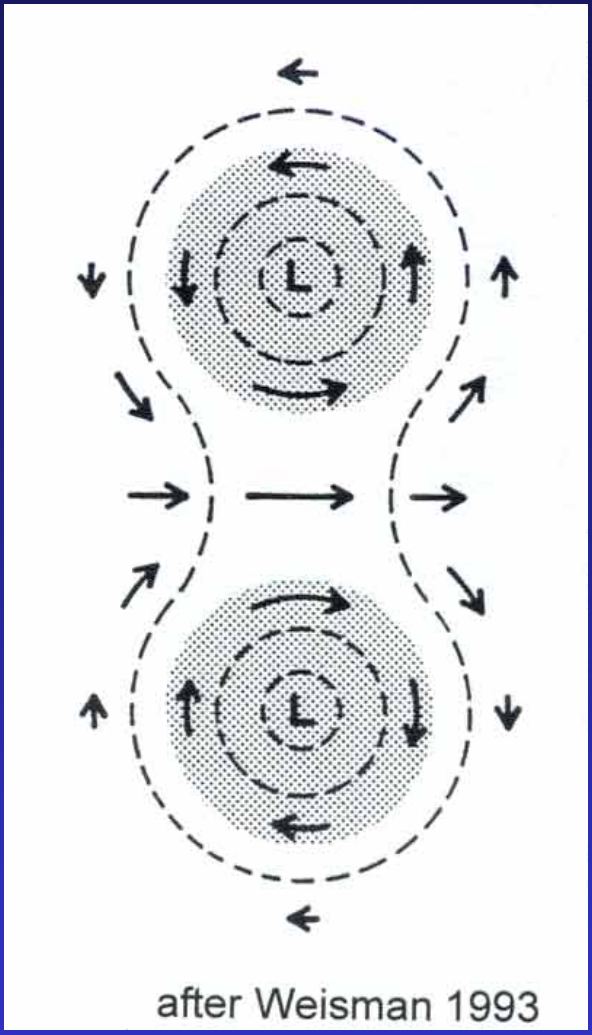


Rotational Velocity (Vr) Trace of Circulation 2a (Line-end Vortex). Magnitudes of Vr are shown in (m/s). Note: some of the strongest rotation was documented below 2 km during the period of 2149 - 2202 UTC. Could this vortex play a role in focusing or enhancing surface wind damage along the southern periphery of the circ.?



Map of Circulation Tracks C1 and C2 and Line-end Vortex C2a across north-central Illinois. Squall line positions are denoted every 30 min. T signifies location of tornadic damage. Significant wind damage (est > 70 kts) occurred over and east of Peoria IL (PIA) across northern Taswell through McLean counties in Illinois (along the southern periphery of the line-end vortex). Wind damage continued downstream for the next 1.5 hours after the demise of the line-end vortex.

Line-End (Bookend) Vortex
(Weisman 1993)



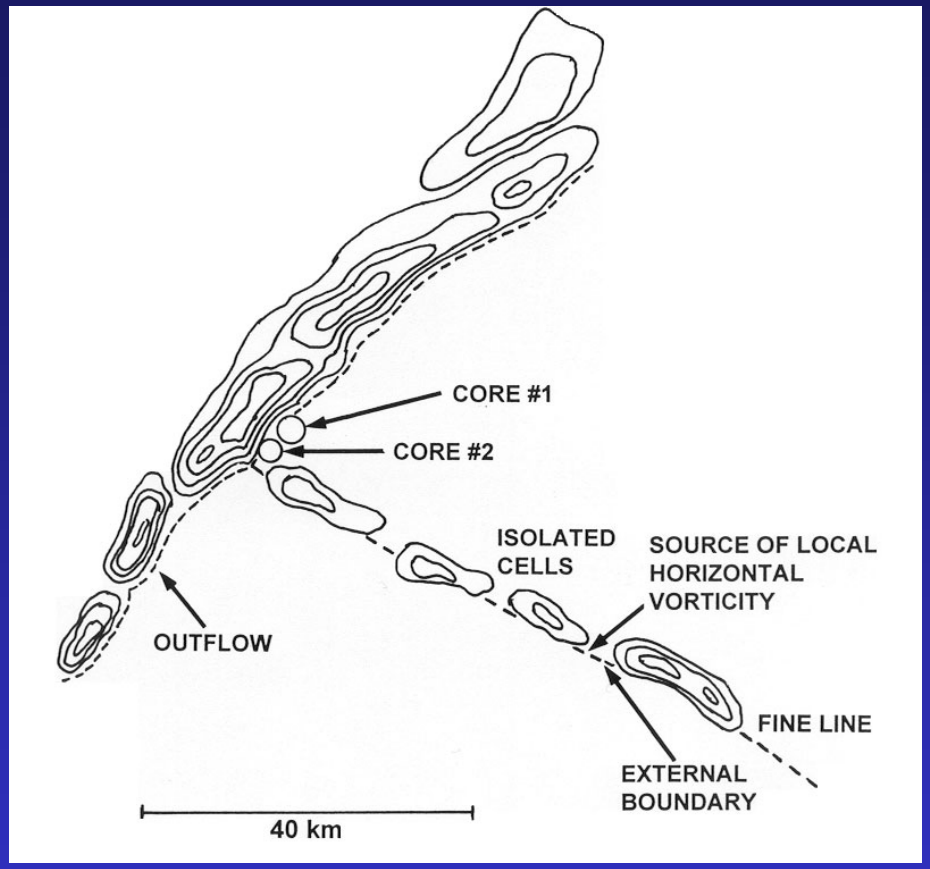
- Velocity field – is a vector sum of the velocity field induced by each vortex.

- Enhancement of the flow between the vortices can be interpreted as a focusing effect of the vortex couplet.

- The strength of the RIJ is dependent on the sizes and magnitudes of the vortices as well as the spacing between them.
- Environmental shear and tilting of ambient horizontal vorticity by updraft – downdraft couplets associated with intense convective cells appear to play roles in the generation of line-end vortices.

2. *Low-level boundary intersecting the southern end of the convective line.*

- **7 cases**
- 5 late evening – early morning events
- 2 late afternoon – early evening events.



a) Reflectivity Characteristics

- Two differing reflectivity patterns:

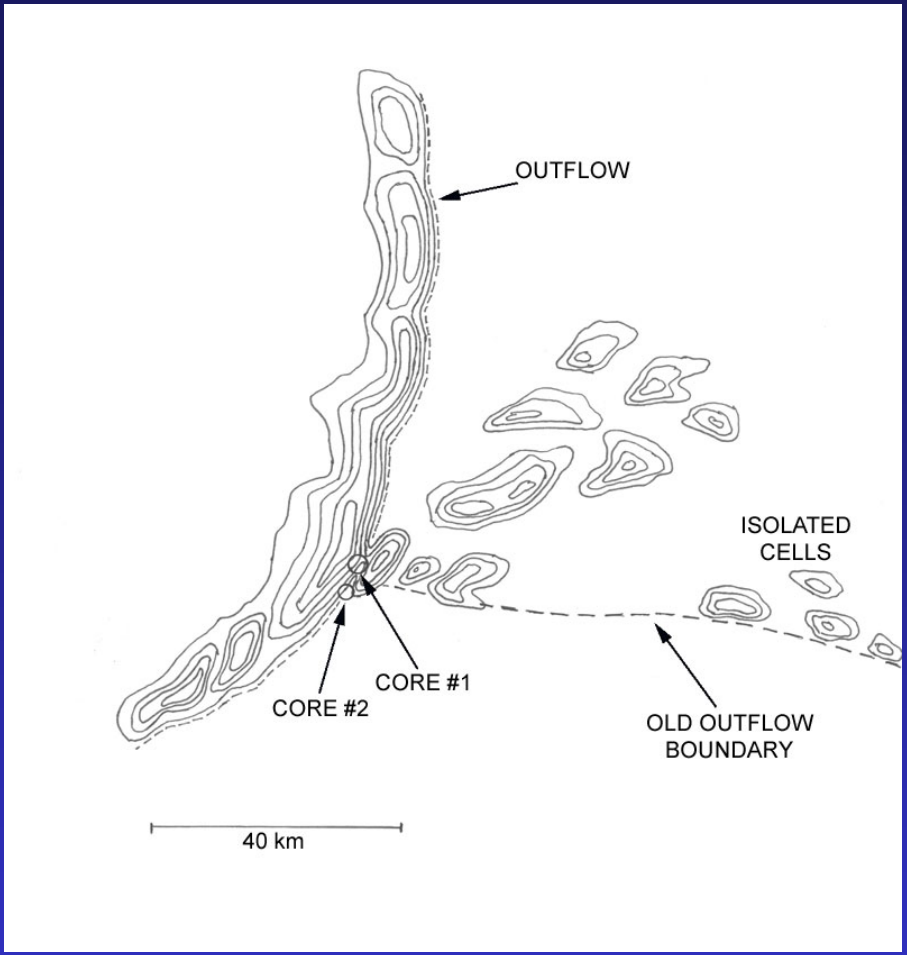
(Pattern #1 – 3 cases)

- line of small isolated cells or reflectivity fine line intersects, and extends downwind from the southern part of the larger convective line.
- line of small isolated cells is frequently oriented *orthogonal* to the larger convective line.

Pattern #2

- Similar to the first pattern except that multiple convective cells are noted well north of the warm frontal or a low-level boundary.

- First and second circulations often form in the vicinity of the boundary – convective line intersection.



- Two of the seven cases support this pattern.

First Reports of damaging winds and initial bowing:

- 29% (2 of the 7 events) north of the low-level boundary – convective line intersection
- 42% (3 of the 7 events) south of the intersection.
- 29% (2 of the 7 events) both north and south of the low-level boundary – convective line intersection.

b) *Circulation Trends:*

-In 6 of the 7 events, first two cores formed in the vicinity of a boundary – convective line intersection.

- In the remaining case, first or second cores were *not* observed in the vicinity of the intersection.

- In 5 of the 7 events, *numerous cores (4 or more)* were identified along the cyclonic shear side of the bow (northern end to near apex of the bow).
- Core 3 and subsequent cores developed *after* the first two cores by 5 to as much as 15 minutes.

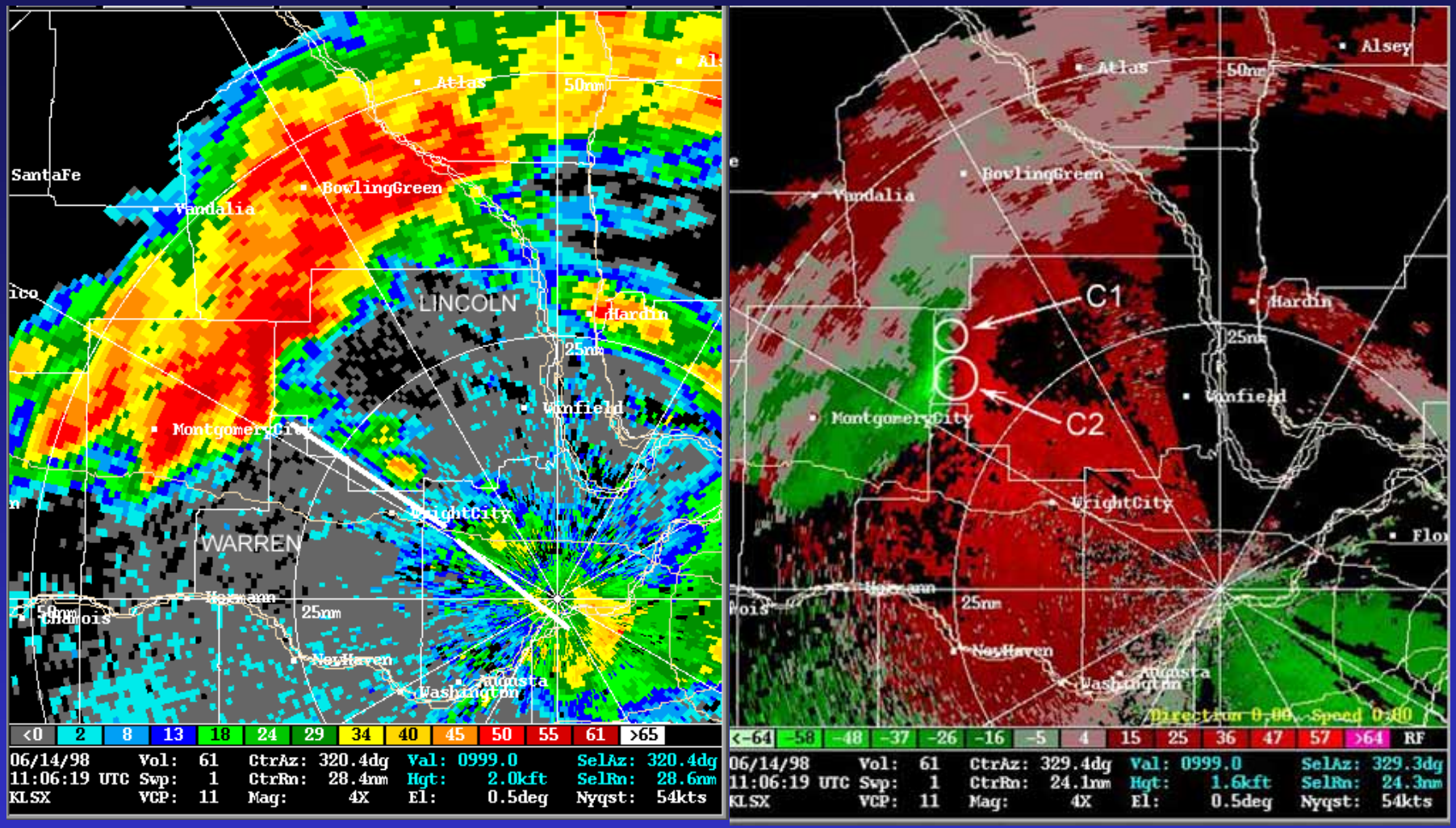
- In the remaining 2 cases, only three cores were documented throughout the bow echo evolution.

b) *Circulation Trends cont'*

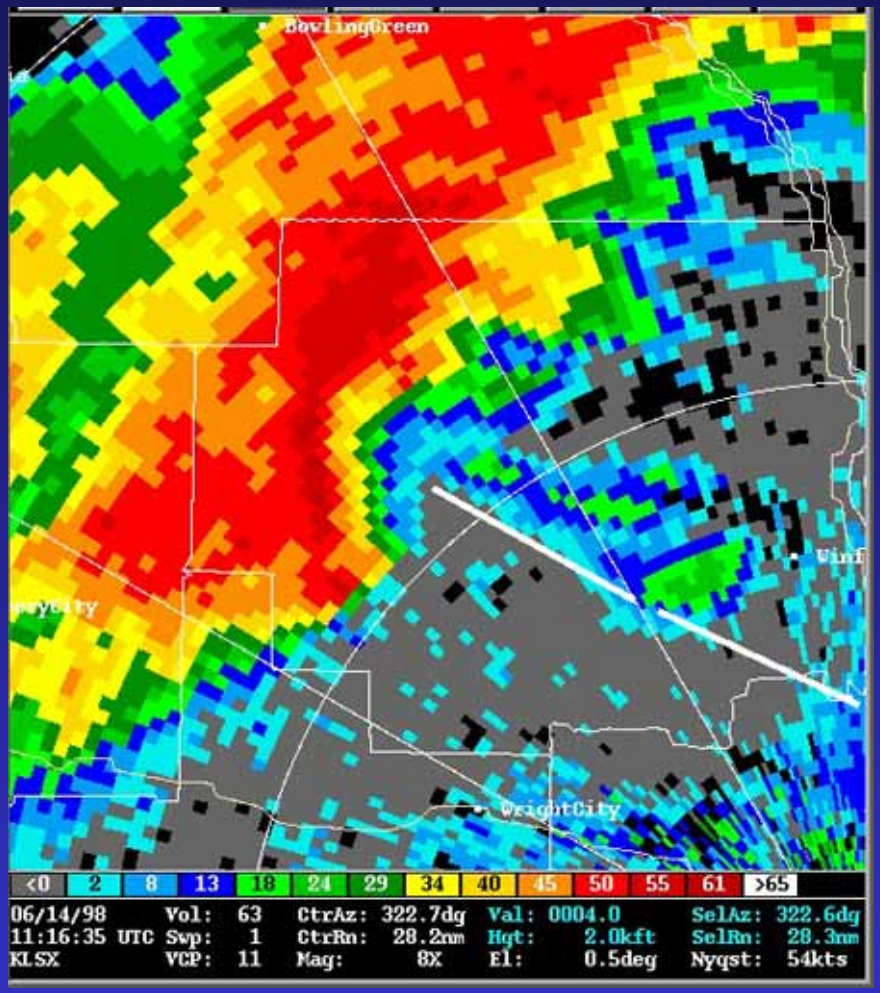
- Non-supercell tornadoes (F0 – F1 damage) occurred in 3 of the 5 *numerous core events* – with Cores 2 and 3 . However, non-supercell tornadoes did not occur with the remaining 2 events.

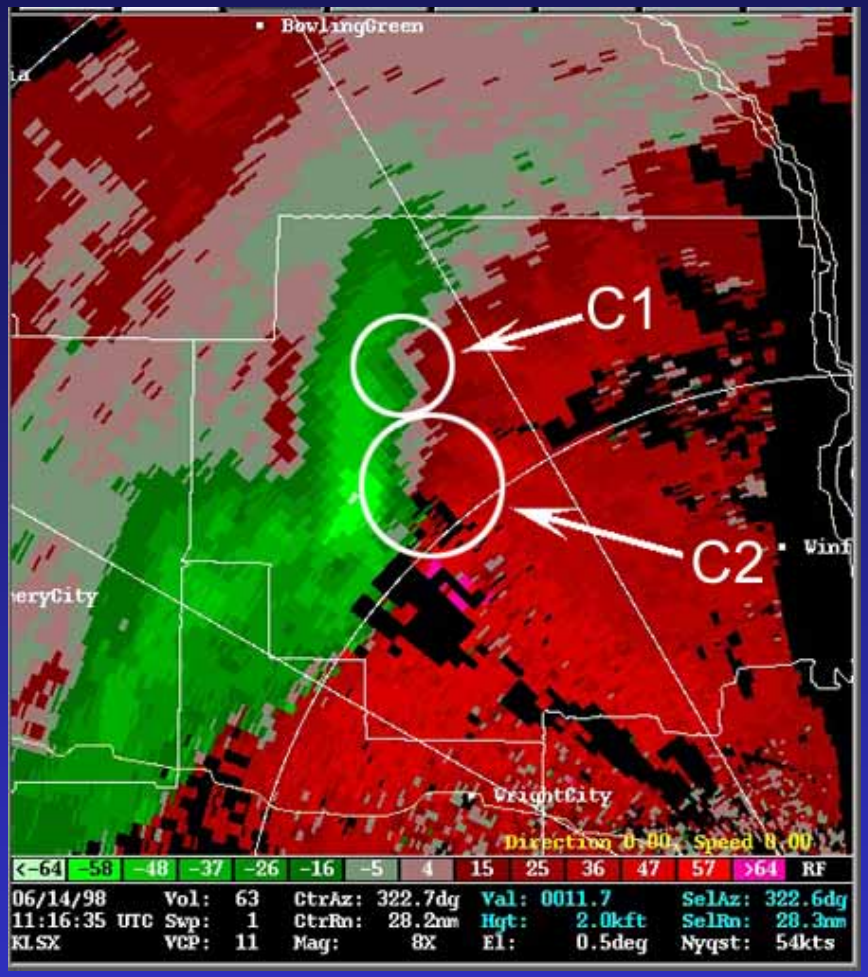
- In all five events – moderate shear was present. However, magnitudes of CAPE ranged from 2200 – 3000 J/kg in 4 cases and near 3500 J/kg in the 5th event.

- Non-supercell tornadoes (F0 – F1 damage) occurred in 1 of the 2 remaining MCS events where only 3 cores were documented.
- Moderate shear was present, and magnitudes of CAPE were 2000 and 3200 J/kg respectively.

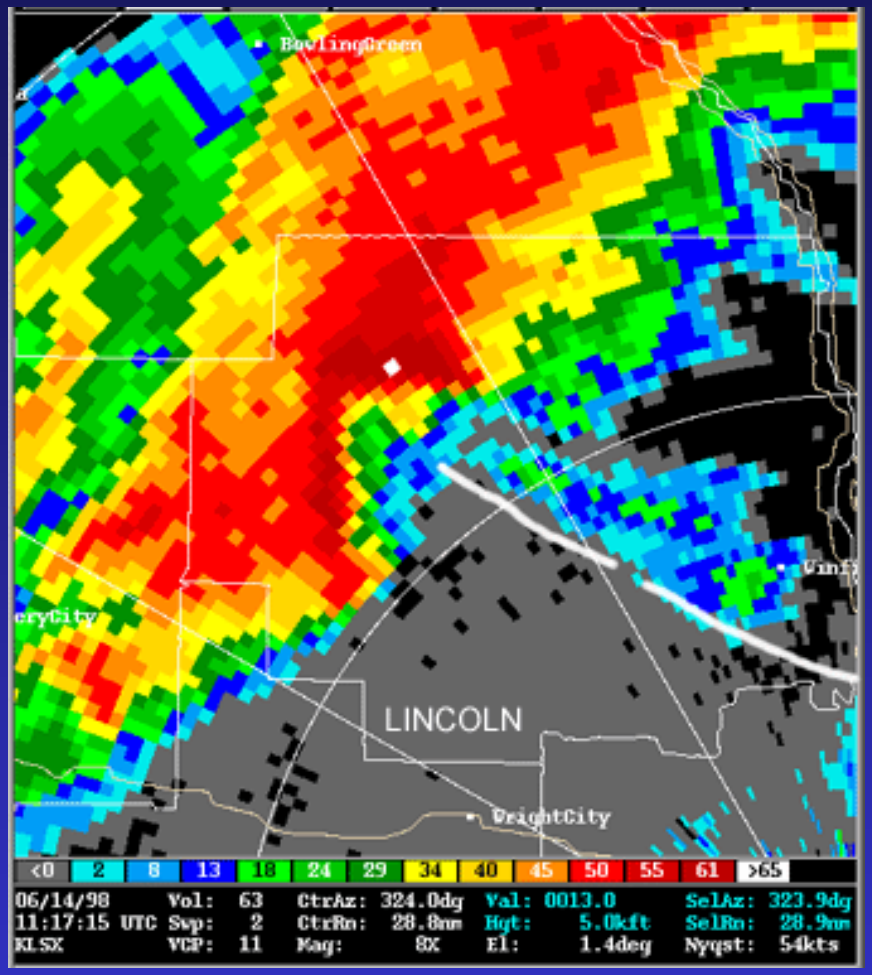


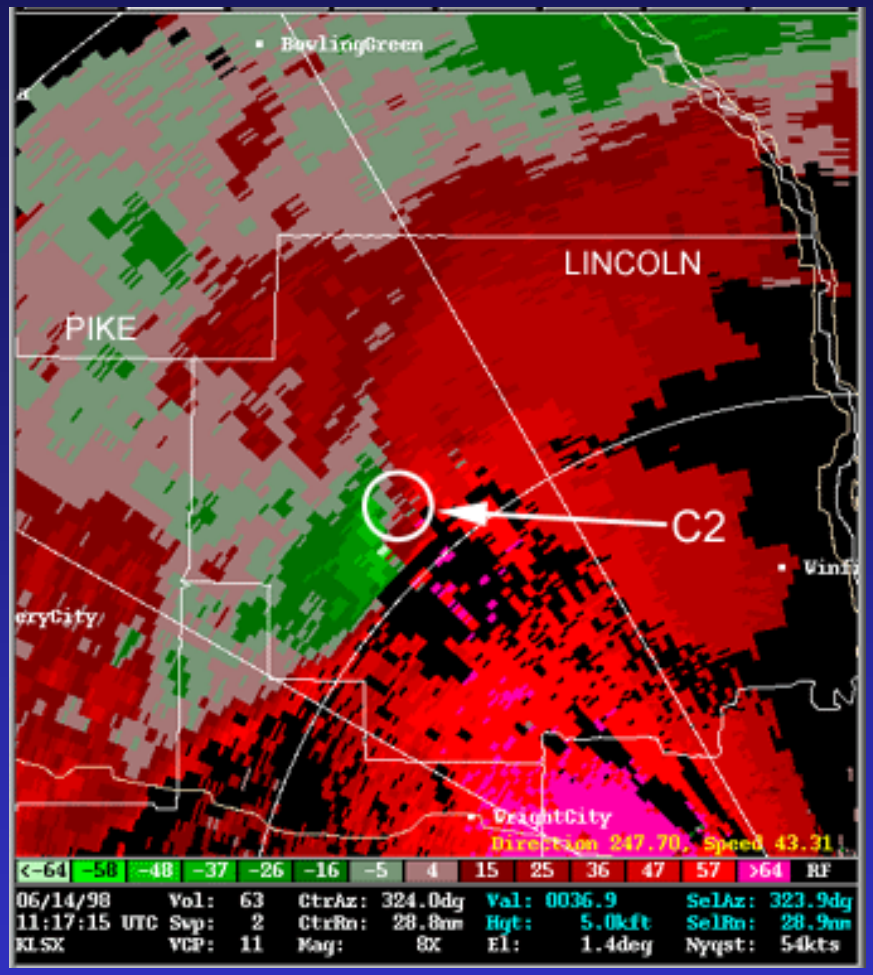
1106 UTC 14 June 1998 reflectivity (0.5° slice) (left); SRM velocity (right) (KLSX). Southern most line of small convective cells, intercepting a strong storm (hybrid supercell?) embedded within the line, appear to reflect location of the low-level boundary. The second parallel line - elevated boundary. **Circulation core #1 and #2** formed with the southern-most line.





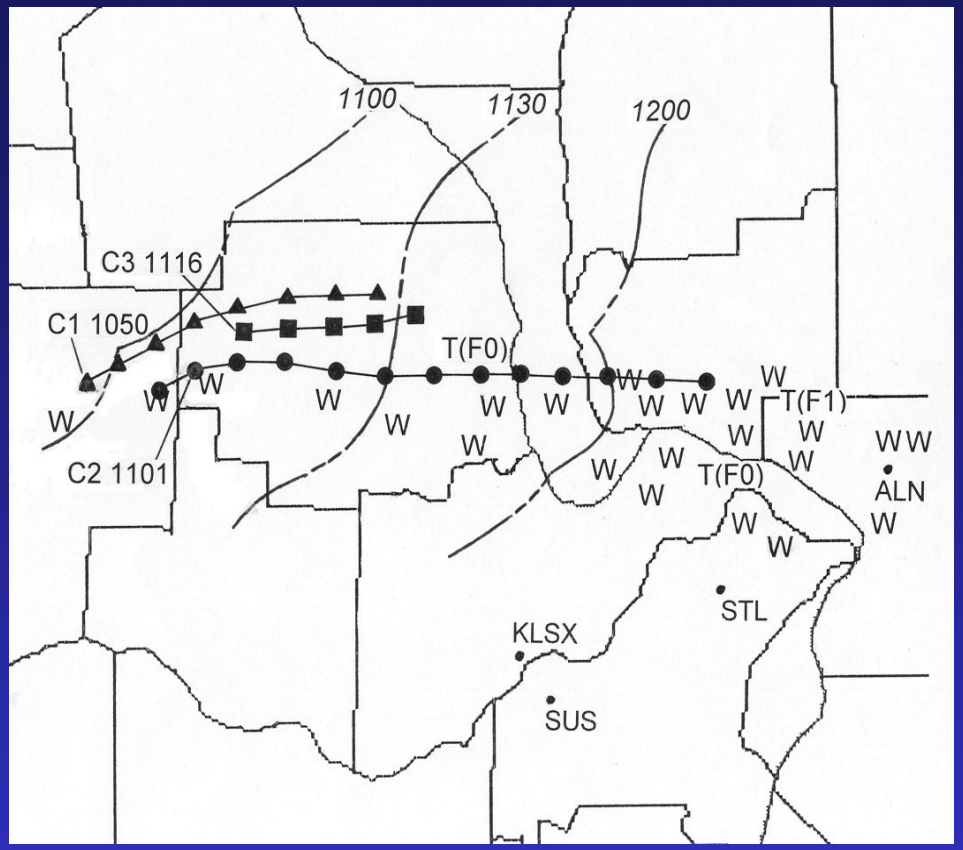
1116 UTC 14 June 1998 reflectivity (0.5° slice) left); storm-relative velocity (0.5° slice) (right). Circulation #2 intensified near the intersection of the smaller line of convective cells and the hybrid storm. As the smaller line of convective cells (external boundary) passed over KLSX, magnitudes of 0-2 km SR helicity increased from 106 m2/s2 (0928 UTC) to 783 m2/s2 (1111 UTC).





1117 UTC 14 June 1998 reflectivity (left); SRM velocity (right) at 1.5° slice. C2 shows a symmetrical velocity pattern at 1.5° slice compared to the cyclonic convergent velocity pattern seen at 0.5° slice. A gate to gate velocity couplet is noted near the southern periphery of C2. Delta-V magnitudes = 48 m s-1.

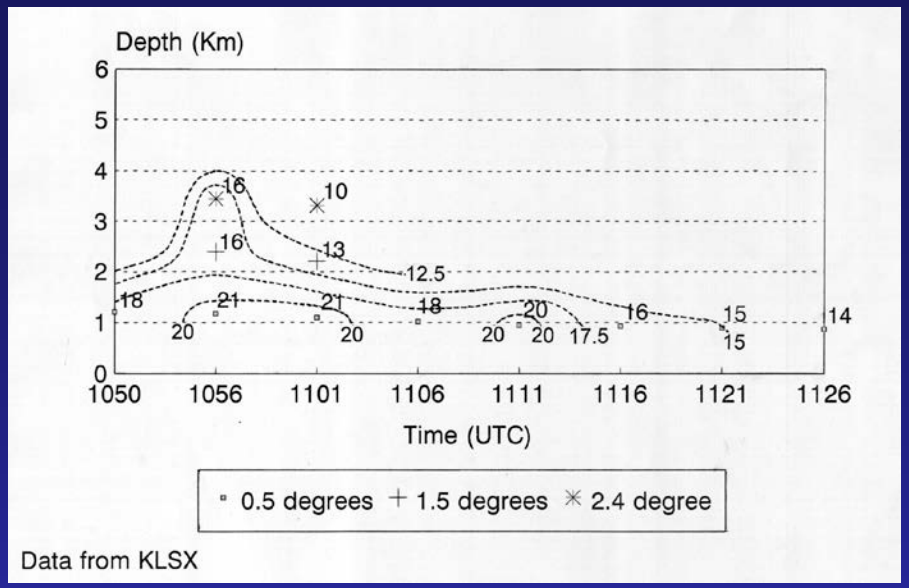
- During the ***later part*** of ***Core #2's mature stage,*** this vortex appeared to play a role in focusing the ***swaths of most intense wind damage.***



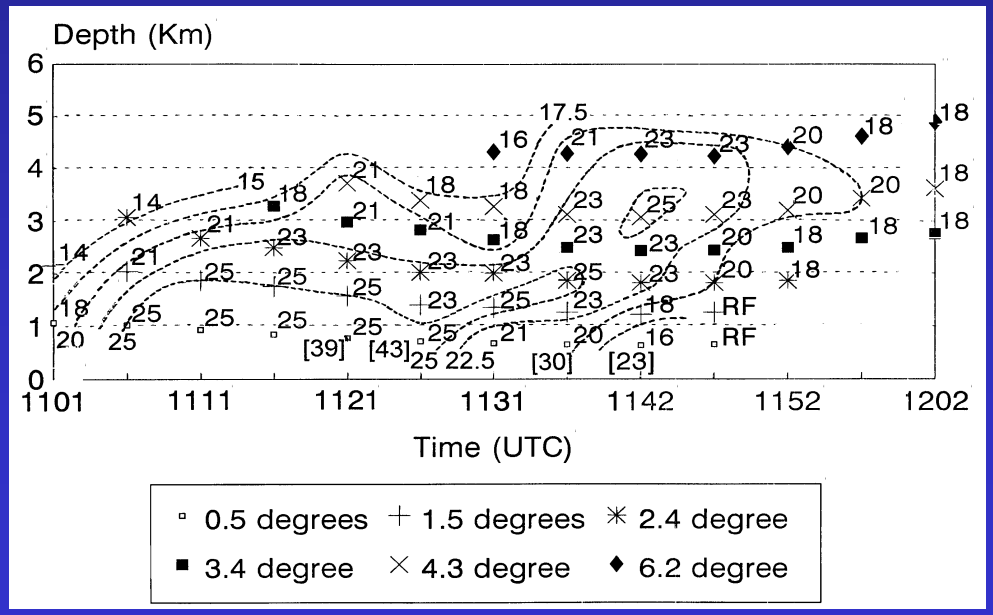
- A **tornado** occurred just prior to the circulation reaching its ***greatest height*** and within the vicinity of *strong low-level rotation* (1131 – 1136 UTC).

Comparison of Mesocyclone Cores #1 and #2.

- **Core #1 –** weaker rotation / shallower depth compared to Core #2.

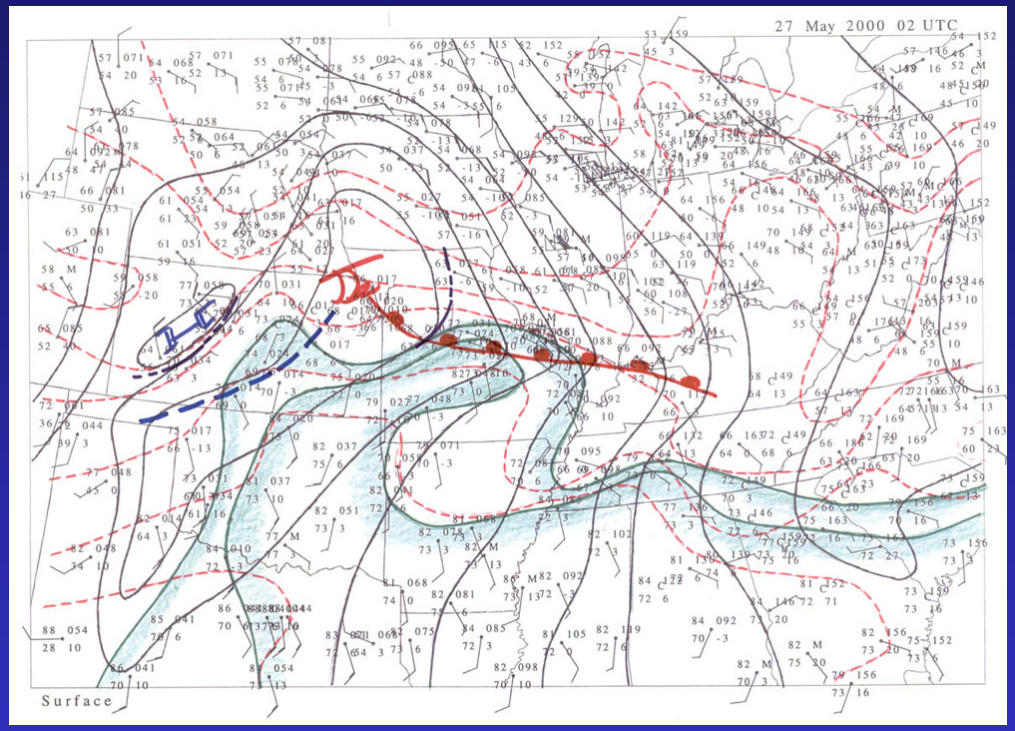


- **Core #2 –** strongest rotation, greatest overall depth and upscale growth *(non-descending)* characteristics. Strongest rotation again was detected within the lowest 2 km.



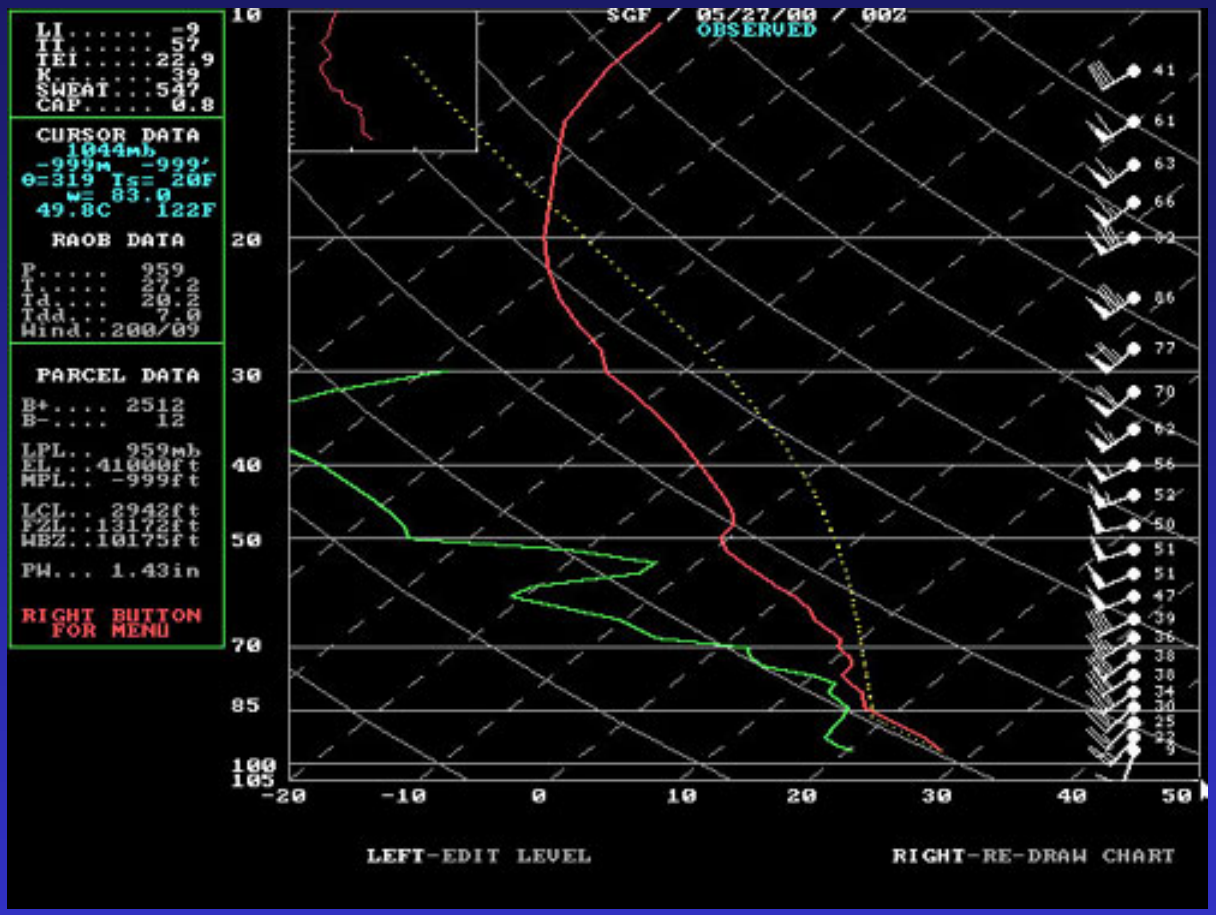
Case #2: 26 May 2000

- Surface analysis
  0200 UTC 27 May 00



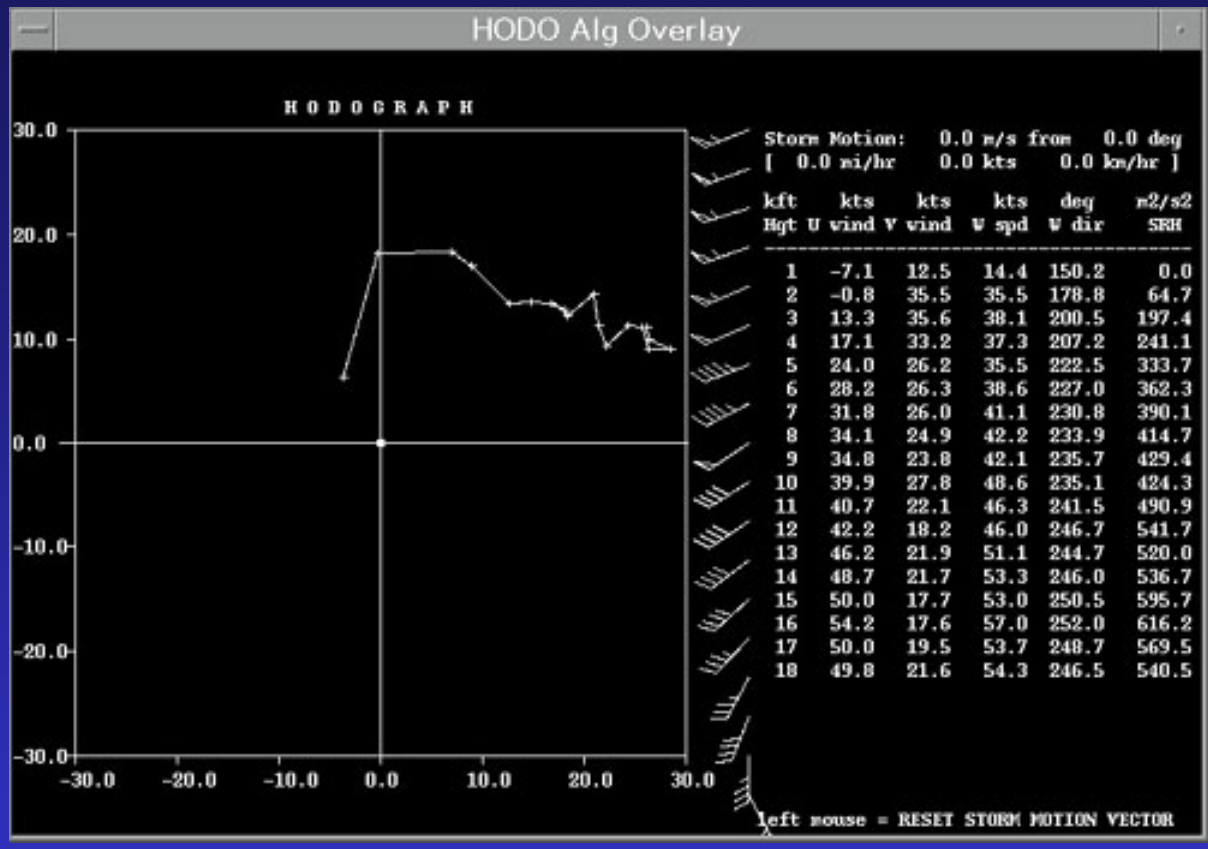
- Warm front draped from surface low over northwest MO east-southeastward into south-central Illinois.
- Surface dewpoints reaching mid 70s pooling near warm front over central and western Missouri.

Skew-T Log P KSGF 0000 UTC 27 May 2000



- Surface-based CAPE 2512 J/Kg
- Mid-level region relatively dry – supportive of damaging winds.
- Bulk Shear (0-3 km) 17 m s-1; (0-5 km) 22 m s-1.

KLSX VWP Profile for 0217 UTC – 27 May 2001



kft Hgt	kts U wind	kts V wind	kts W spd	deg W dir	m2/s2 SRH
1	-7.1	12.5	14.4	150.2	0.0
2	-0.8	35.5	35.5	178.8	64.7
3	13.3	35.6	38.1	200.5	197.4
4	17.1	33.2	37.3	207.2	241.1
5	24.0	26.2	35.5	222.5	333.7
6	28.2	26.3	38.6	227.0	362.3
7	31.8	26.0	41.1	230.8	390.1
8	34.1	24.9	42.2	233.9	414.7
9	34.8	23.8	42.1	235.7	429.4
10	39.9	27.8	48.6	235.1	424.3
11	40.7	22.1	46.3	241.5	490.9
12	42.2	18.2	46.0	246.7	541.7
13	46.2	21.9	51.1	244.7	520.0
14	48.7	21.7	53.3	246.0	536.7
15	50.0	17.7	53.0	250.5	595.7
16	54.2	17.6	57.0	252.0	616.2
17	50.0	19.5	53.7	248.7	569.5
18	49.8	21.6	54.3	246.5	540.5

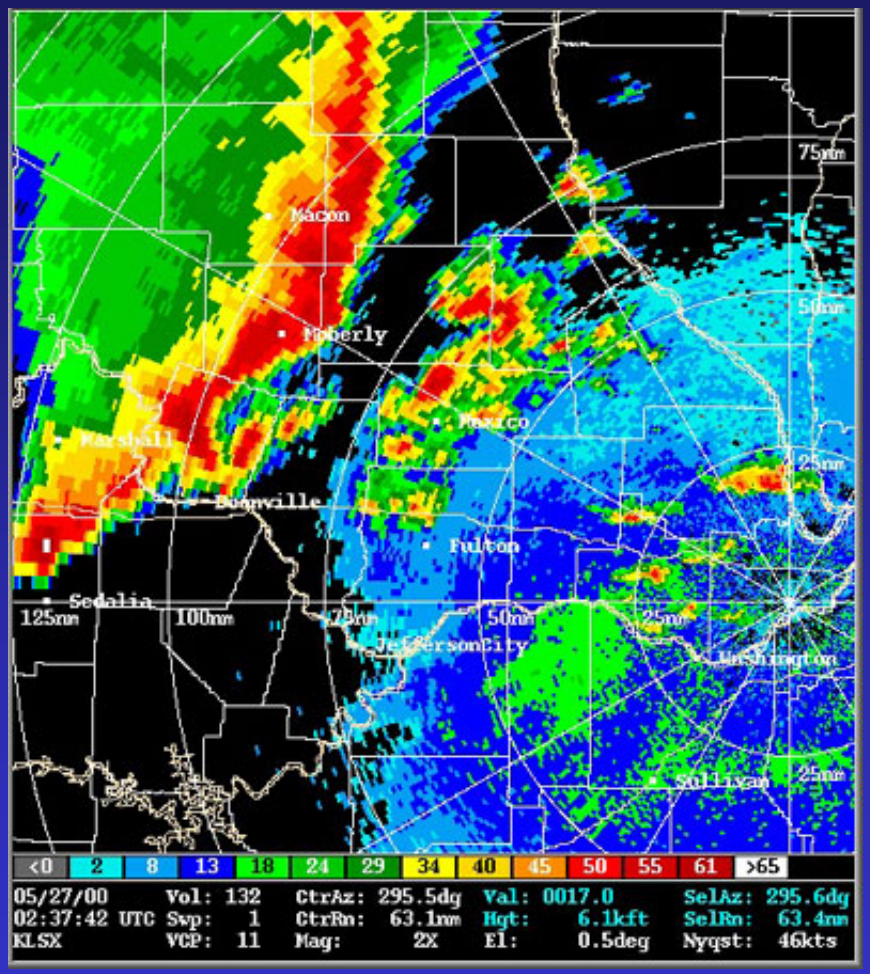
- 0-2 km SRH 362 m^2s^{-2}
- 0-3 km SRH 424 m^2s^{-2}
- Note ‘kink’ in lowest 2 kft of hodograph
- Roger Edwards and Rich Thompson from SPC have observed this type of hodograph structure in supercells.
- The ‘kink’ represents a transition from strong *speed shear / little directional shear* to *stronger directional shear / weaker speed shear*.

WSR-88D Archived level II data from KLSX

- A large mature squall line entered northeast through central Missouri after 0200 UTC.

- Several smaller bowing segments were embedded within the larger line.

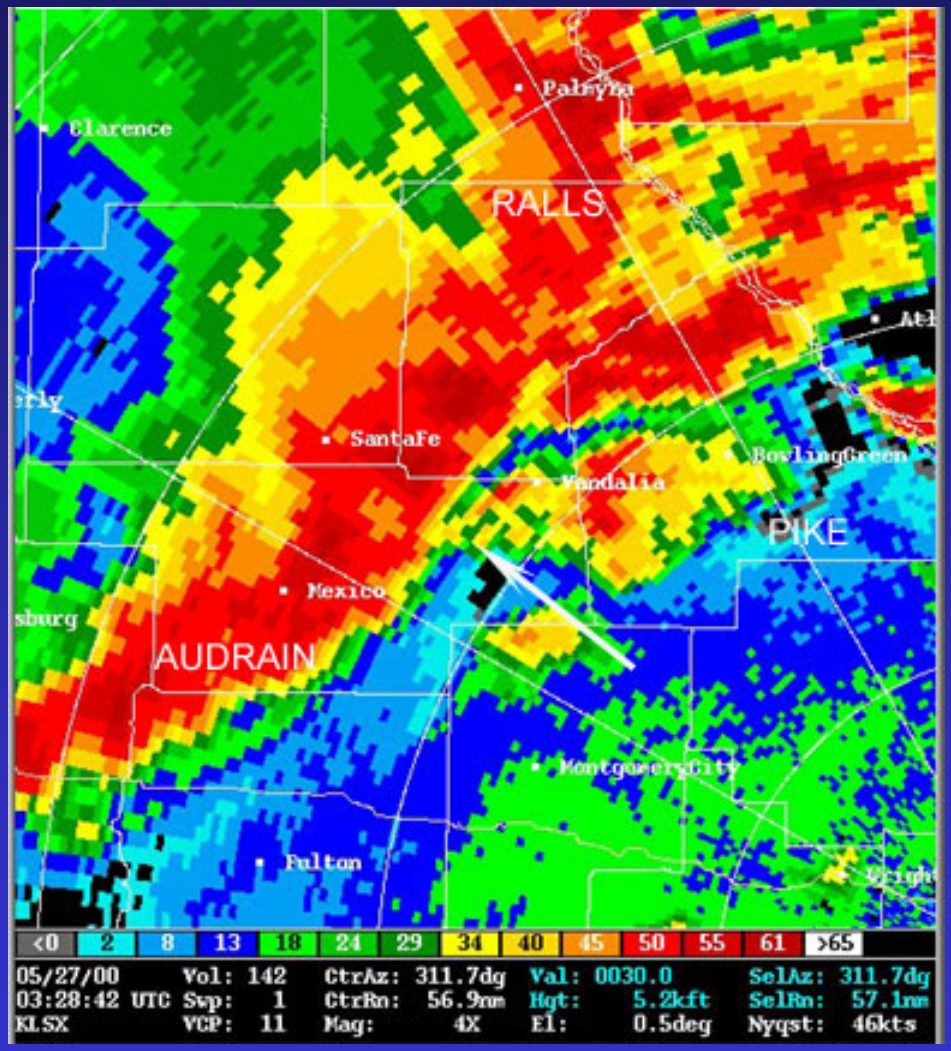
- Bands or areas of smaller convective cells extended between Columbia (COU) and Quincy IL (UIN) and northwest of St. Louis. (just north of the warm frontal boundary)



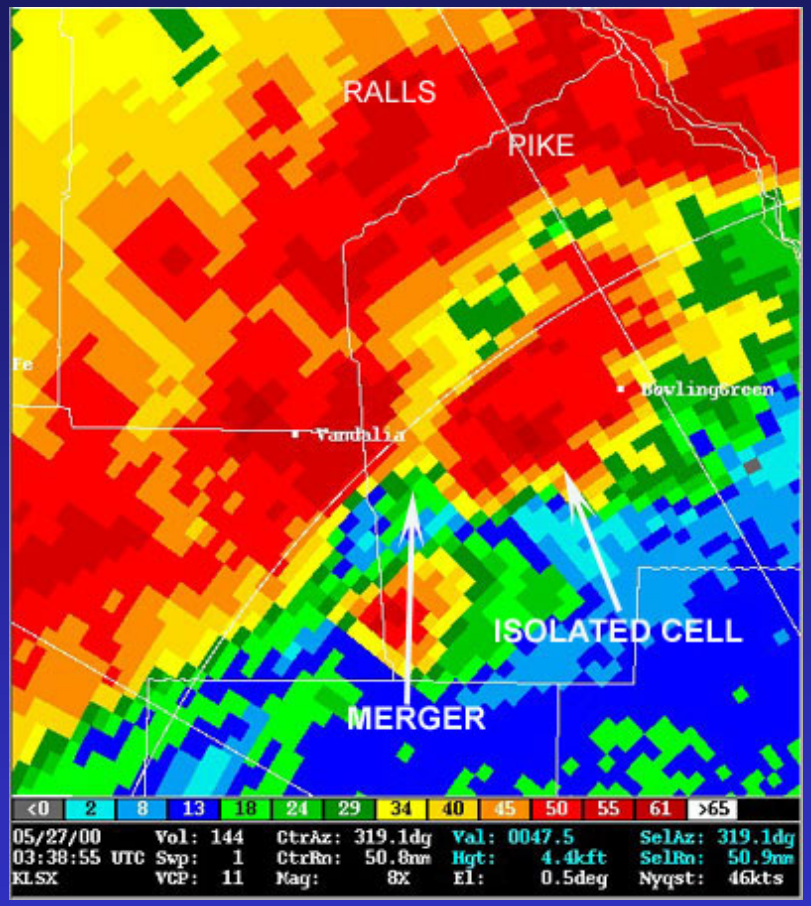
0237 UTC 27 May 2000

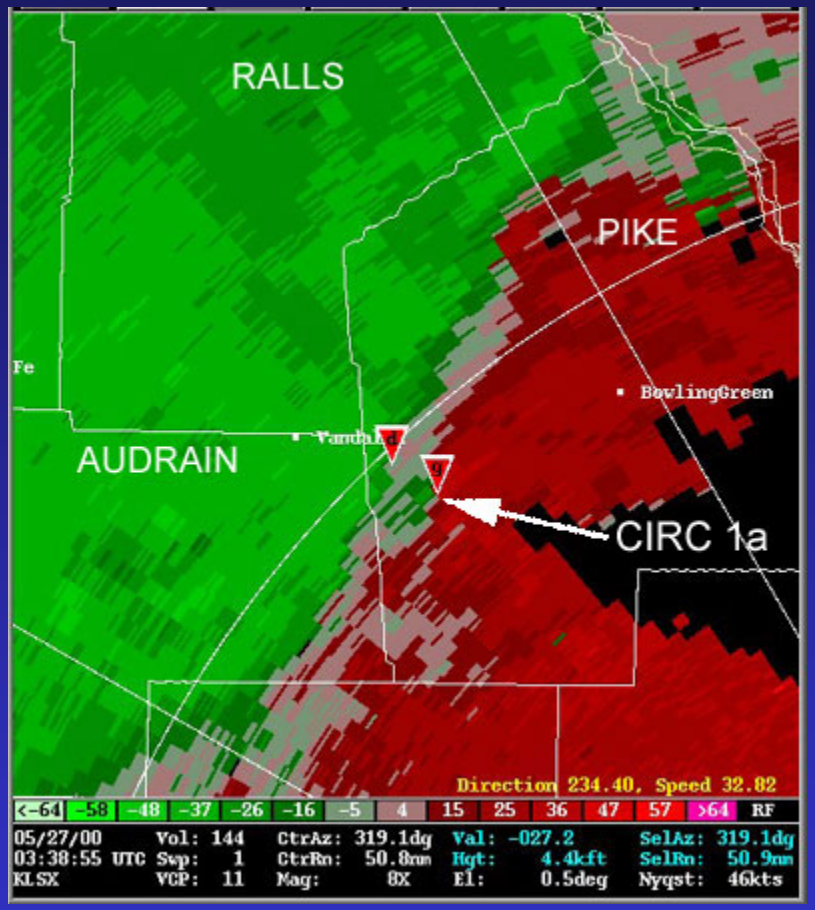
KLSX Reflectivity Image 0328 UTC

- Keyed upon the region of isolated cells – convective line mergers (eastern Audrain county).



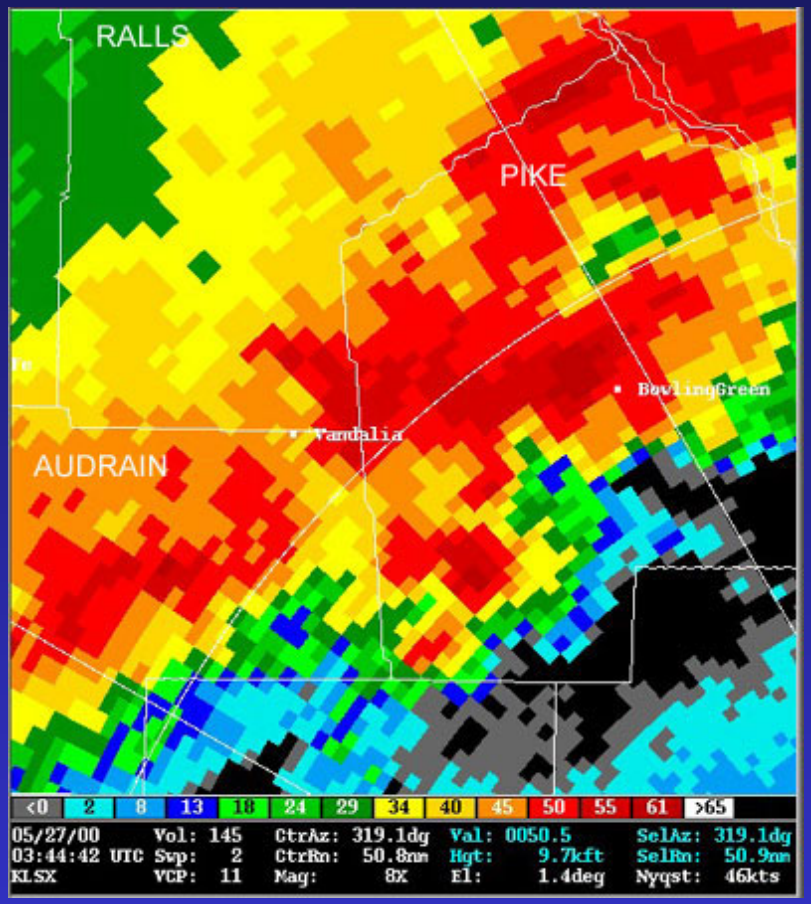
KLSX Reflectivity / SRM 0338 UTC / 0.5° slice

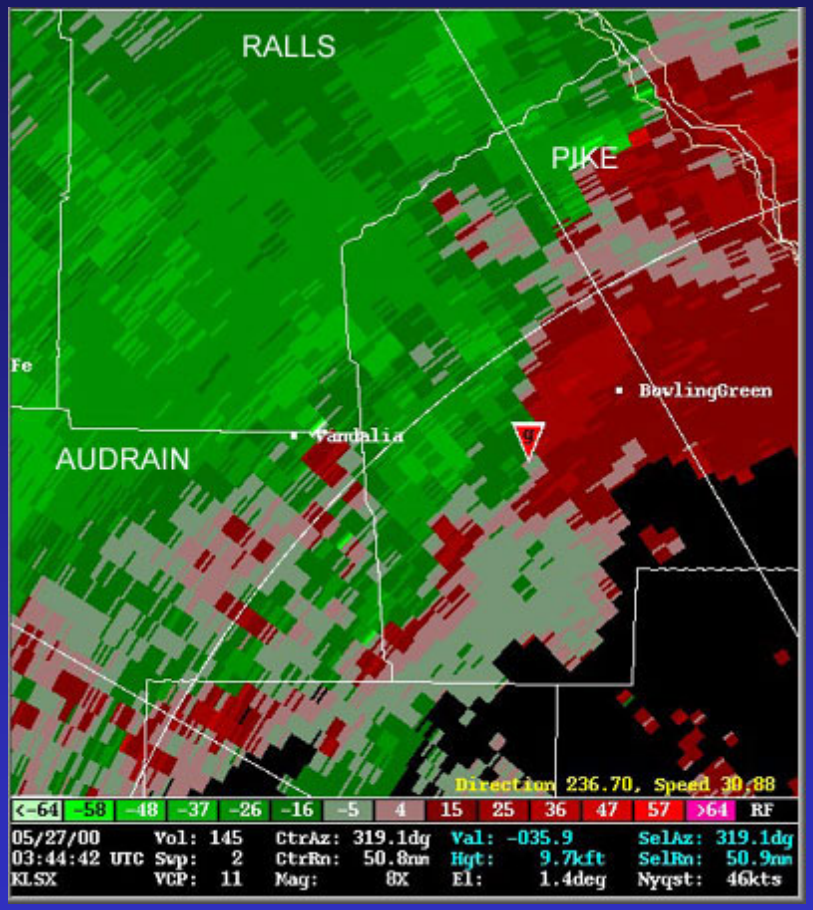




- Second of two isolated cells intensify just prior to merger.
- Small vortex (Circ 1a) formed near the southwest flank of the larger isolated cell. TVS trips (2nd time) near the merger. Yet no tornado or damage was noted in the vicinity of the TVS.

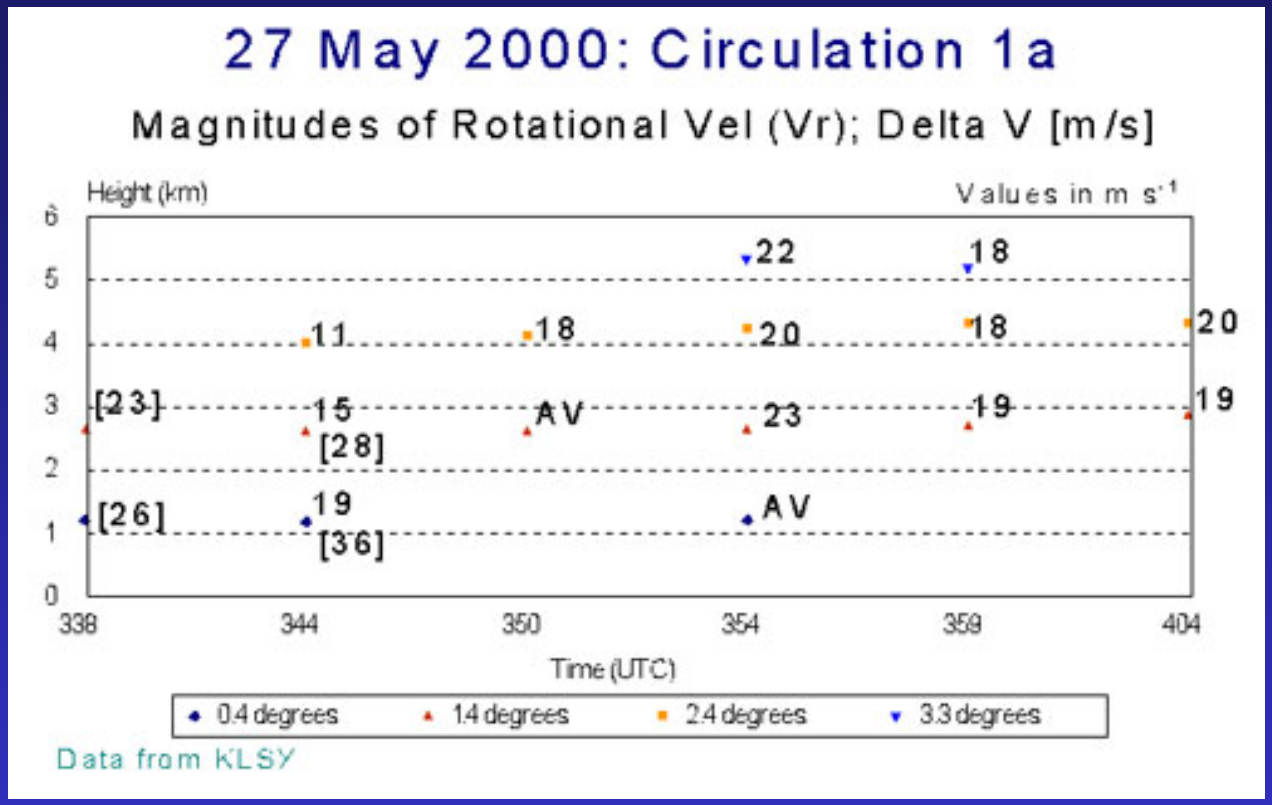
KLSX reflectivity / SRM velocity 0344 UTC / 0.5° slice





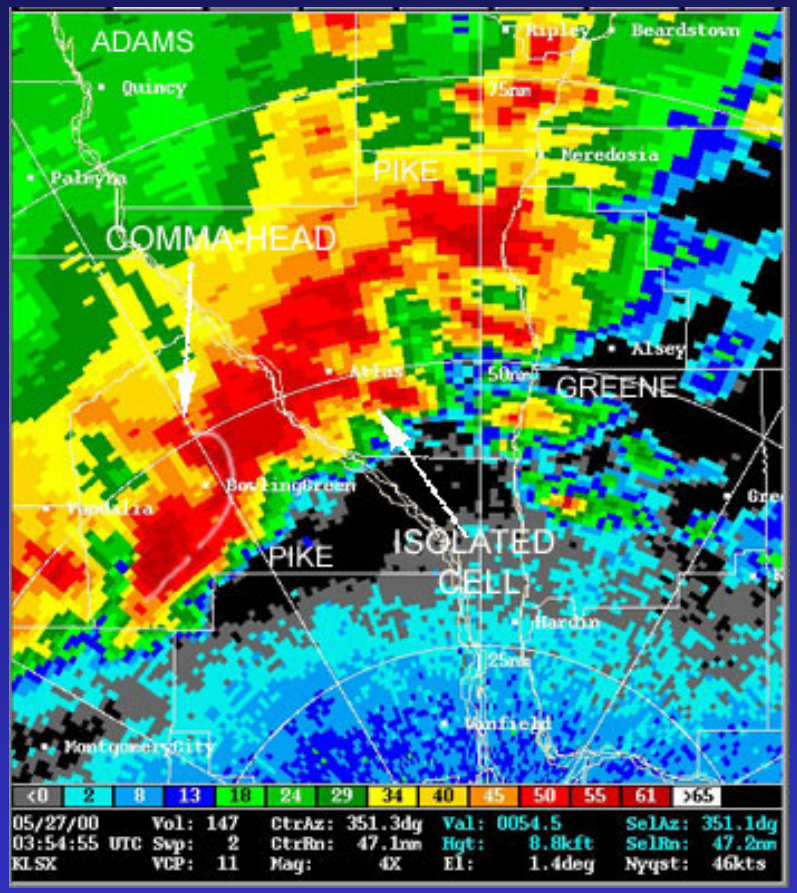
- Merger is complete
- However C1a continued to be evident.
  A TVS trips a third time near the remains of the southern flank of the isolated cell – convective line merger.

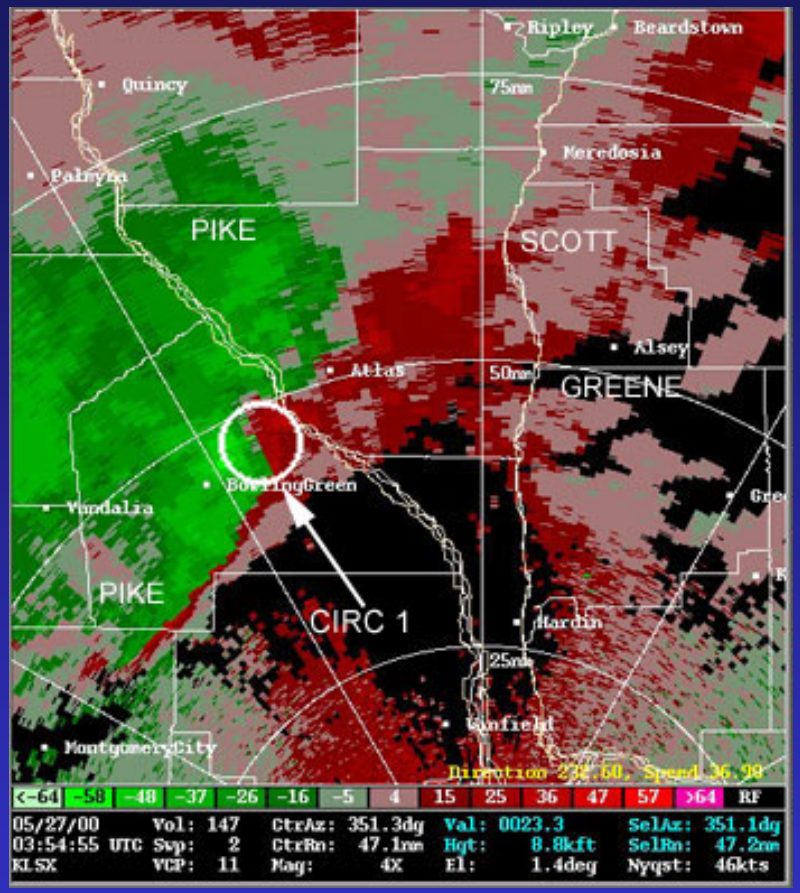
Rotational Velocity Time-Height trace for Circ 1a



- Circ 1a initially formed as a tornadocyclone
- Strongest gate-to-gate shears were detected at 0344 UTC at the lowest 2 elevation slices.
- No tornadic damage was noted at the time of strongest shears. AV – aliased velocities.

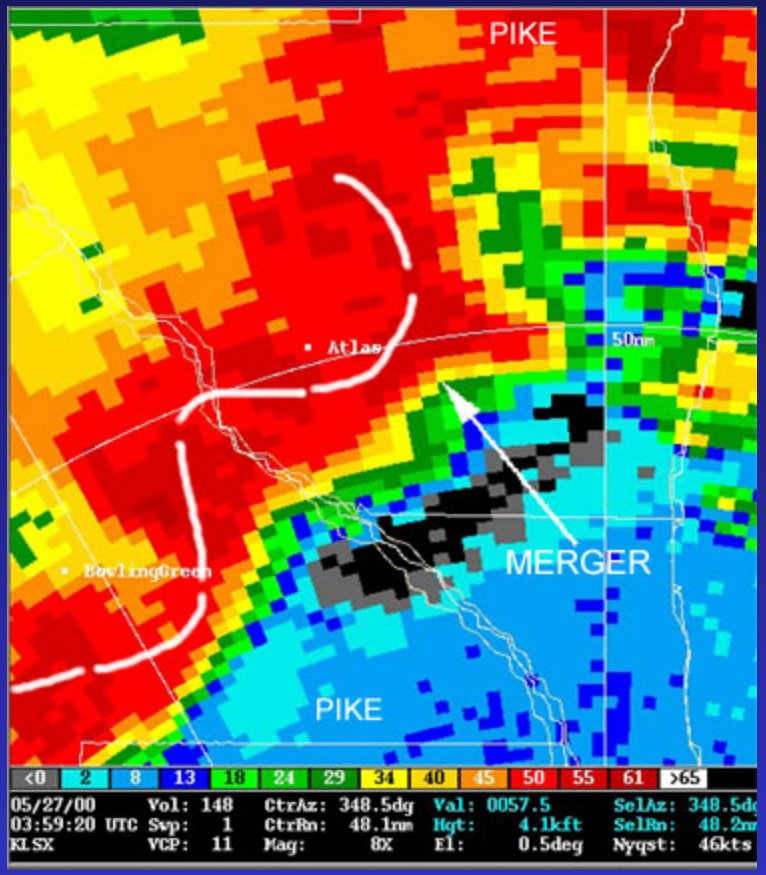
KLSX Reflectivity / SRM 0354 UTC / 1.5° slice

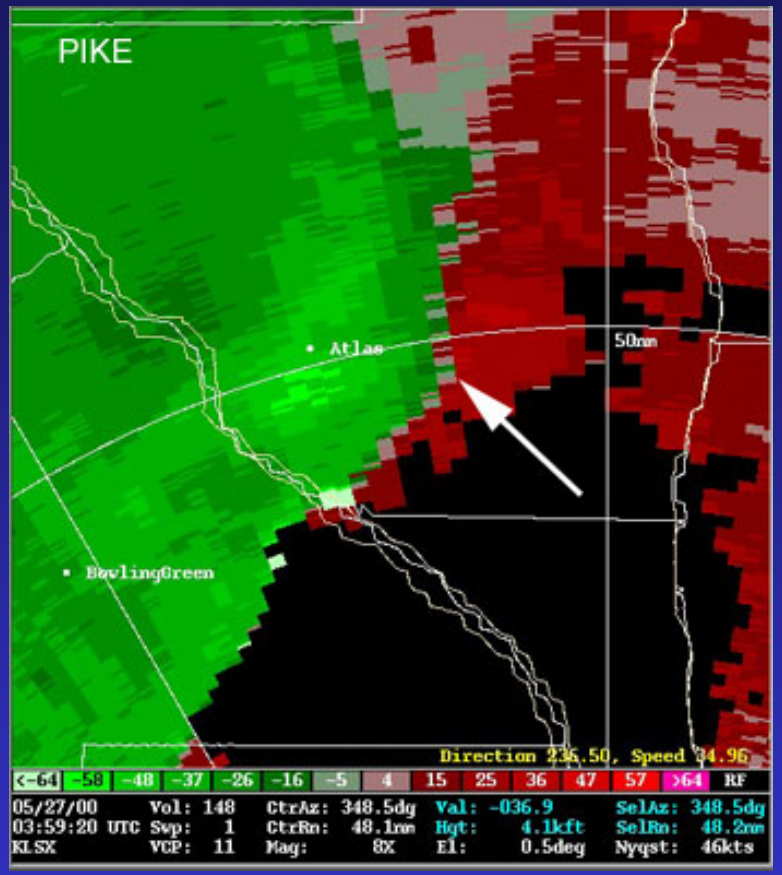




- Band of weaker cells extending from southern Pike through northern Greene Co IL is nearly orthogonal to the larger line.
- An isolated cell within the band intensified just prior to merger.
- Circ 1a, becomes a broad vortex located in the vicinity of the comma-head.
- YET – *no wind damage was reported with this segment.*

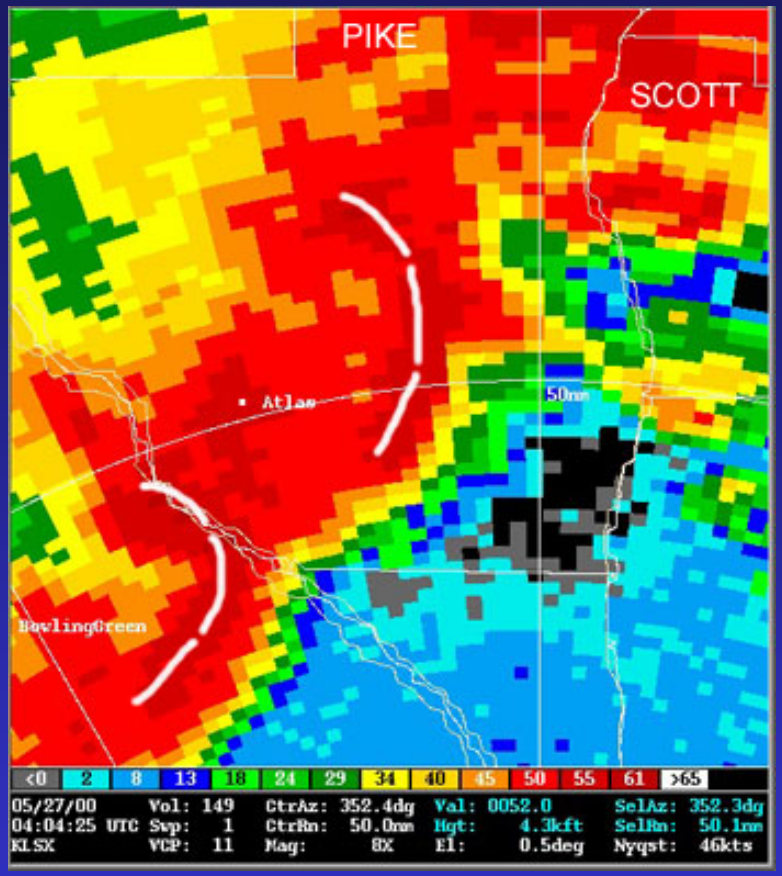
KLSX Reflectivity / SRM 0359 UTC / 0.5° slice

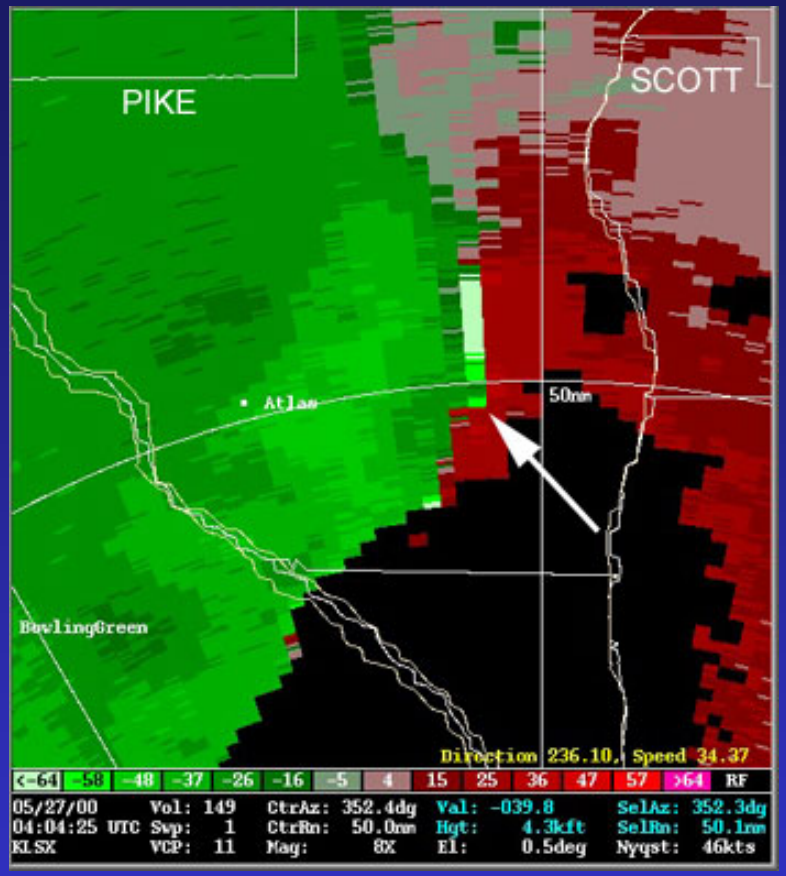




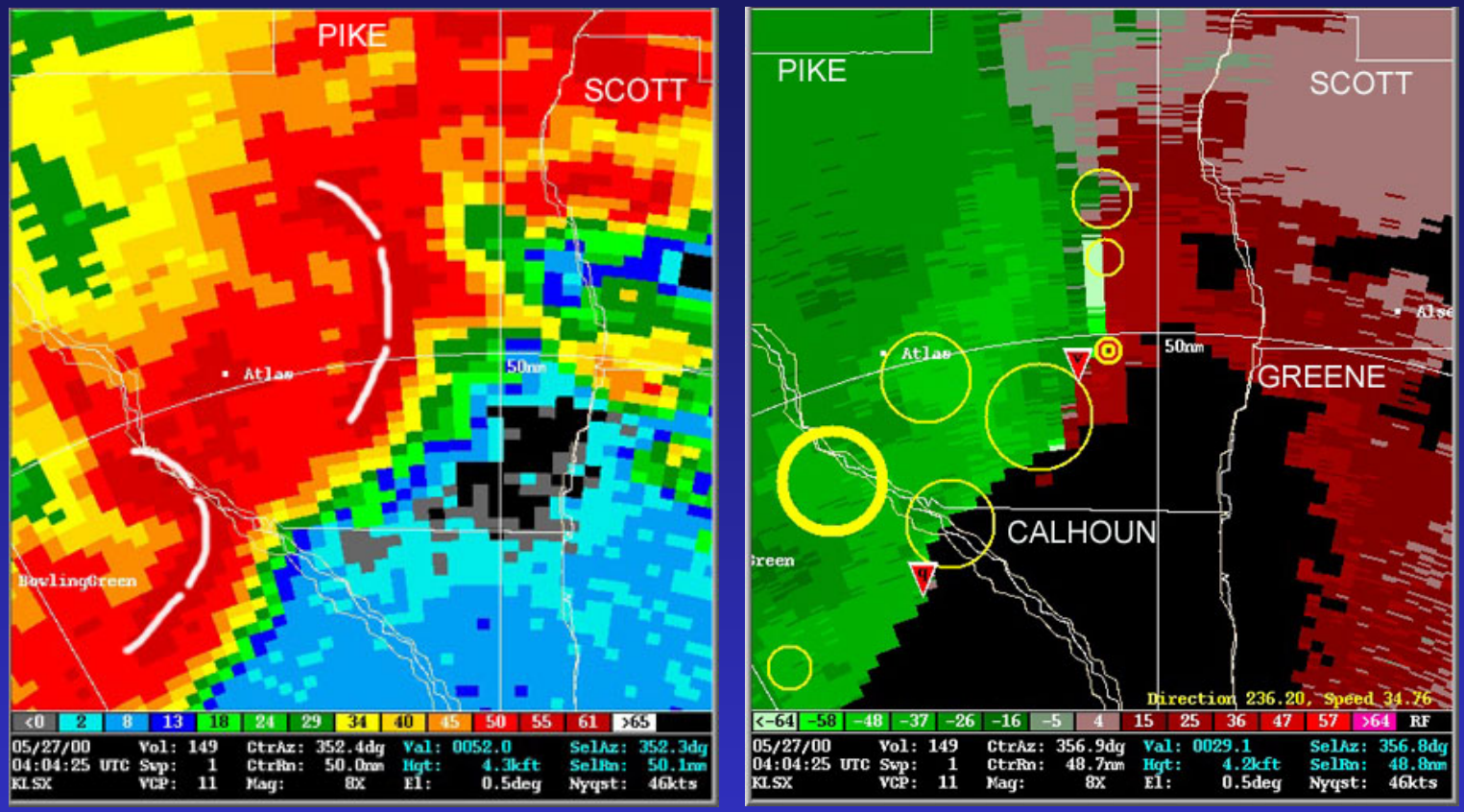
- Second northern bowing segment forms northeast of the first segment.
- Merger is complete between the isolated cell – northern BE.
- Very small vortex (Circ 2) formed just southeast of this merger.
- Wind damage occurred with the northern BE and not the first.

KLSX Reflectivity / SRM 0404 UTC / 0.5° slice



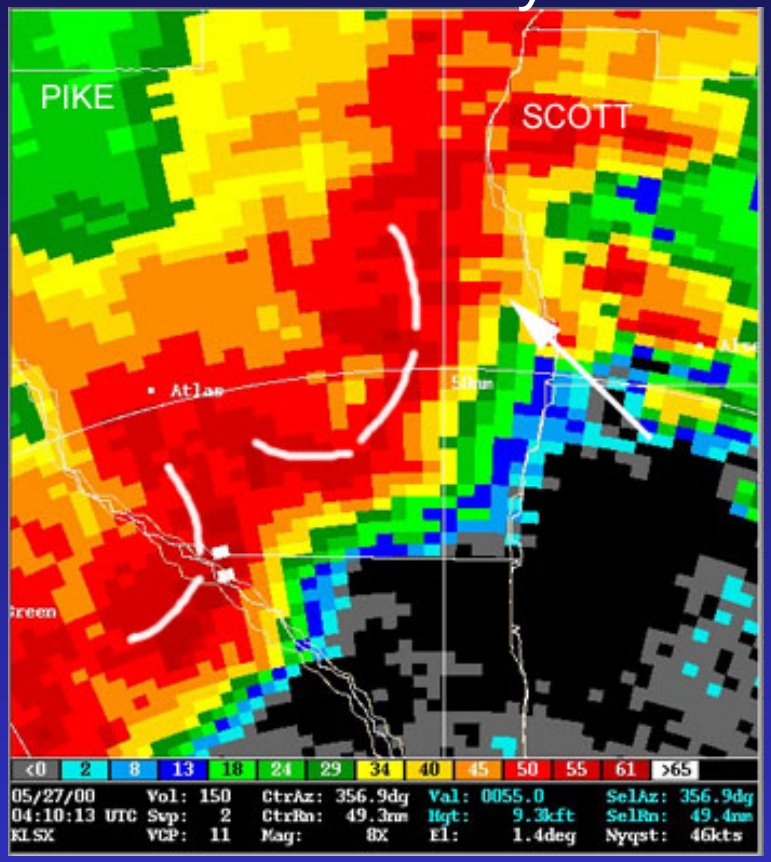


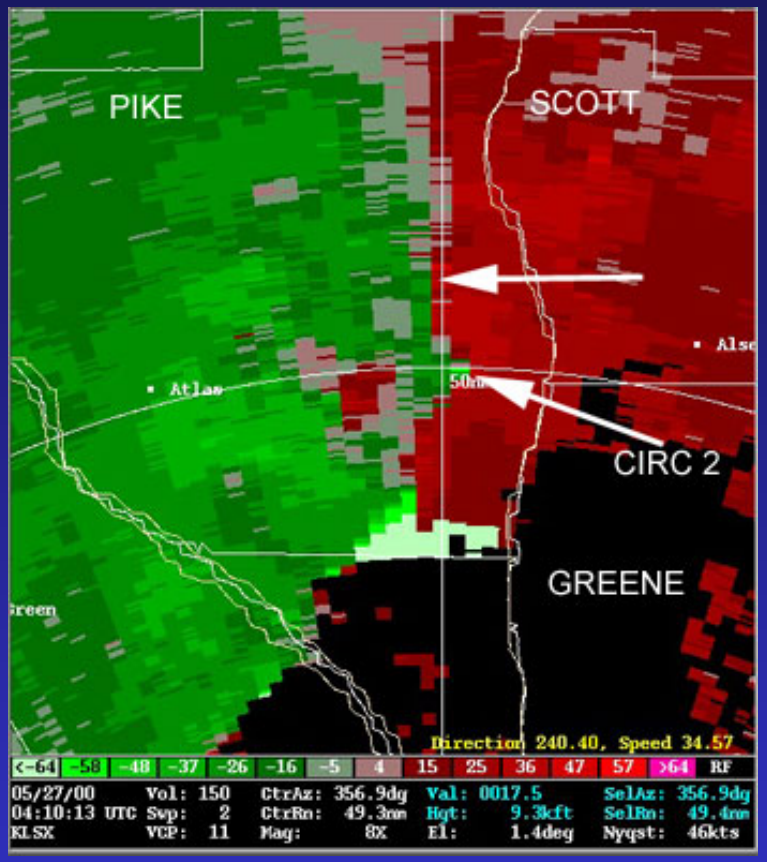
- Northern BE showed slight acceleration compared to the southern BE. Wind damage was associated with this segment.
- Circ 2 intensified along the southern flank of the northern BE (Core diameter very small < 1.0 km).



KLSX reflectivity / SRM 0404 UTC / 0.5° slice with NSSL Meso and TVS (TDA output).

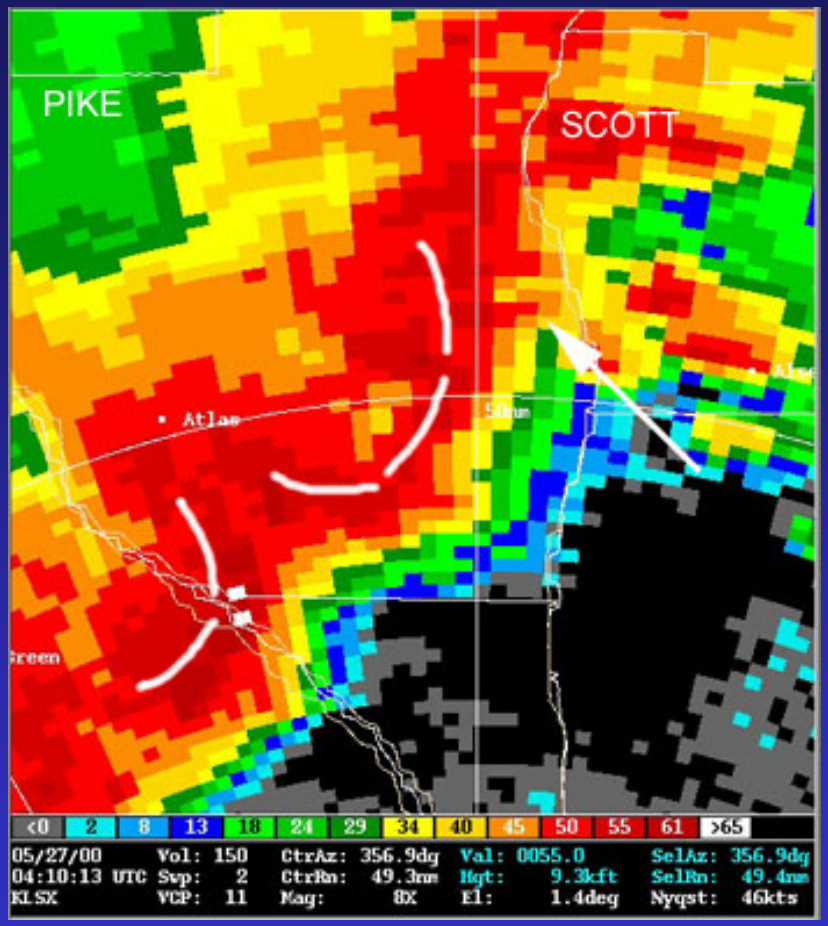
KLSX Reflectivity / SRM 0410 UTC / 1.5° slice

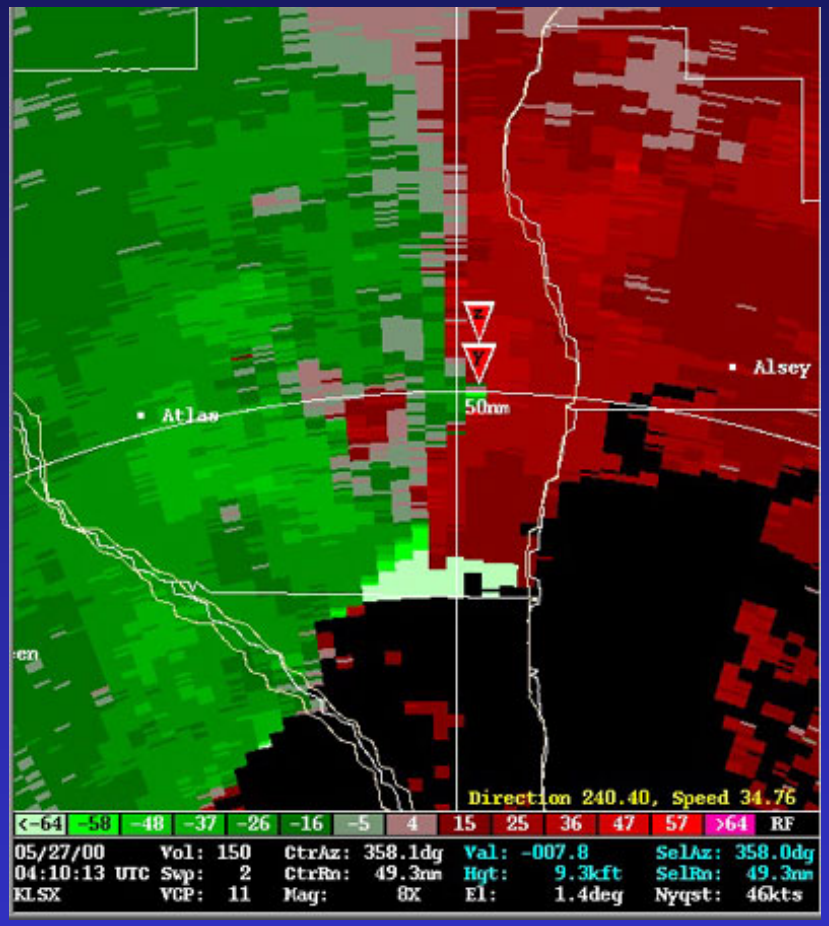




- Circ 2 located just south of the apex maintains a very small core diameter (1.0 km) (Delta V at 1.5° slice 51 m s^{-1}). (tornadocyclone).
- Circ 2 spawned a weak tornado (F1 damage) at 0412 UTC
- A third new small vortex formed near the intersection of isolated cell – larger convective line (C3).

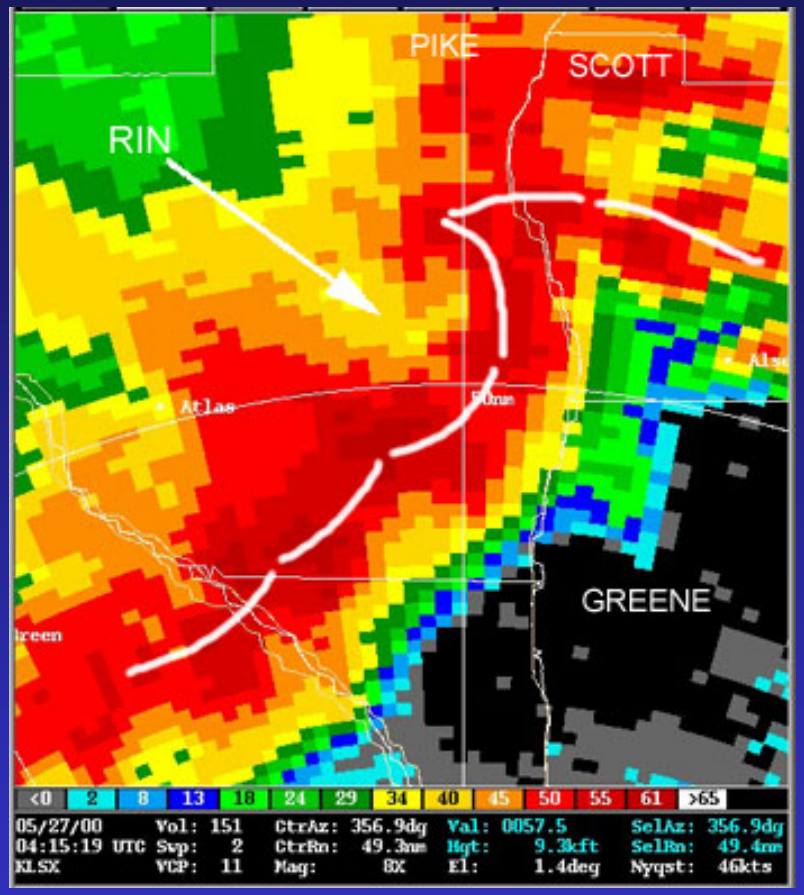
KLSX Reflectivity / SRM 0410 UTC / 1.5° slice

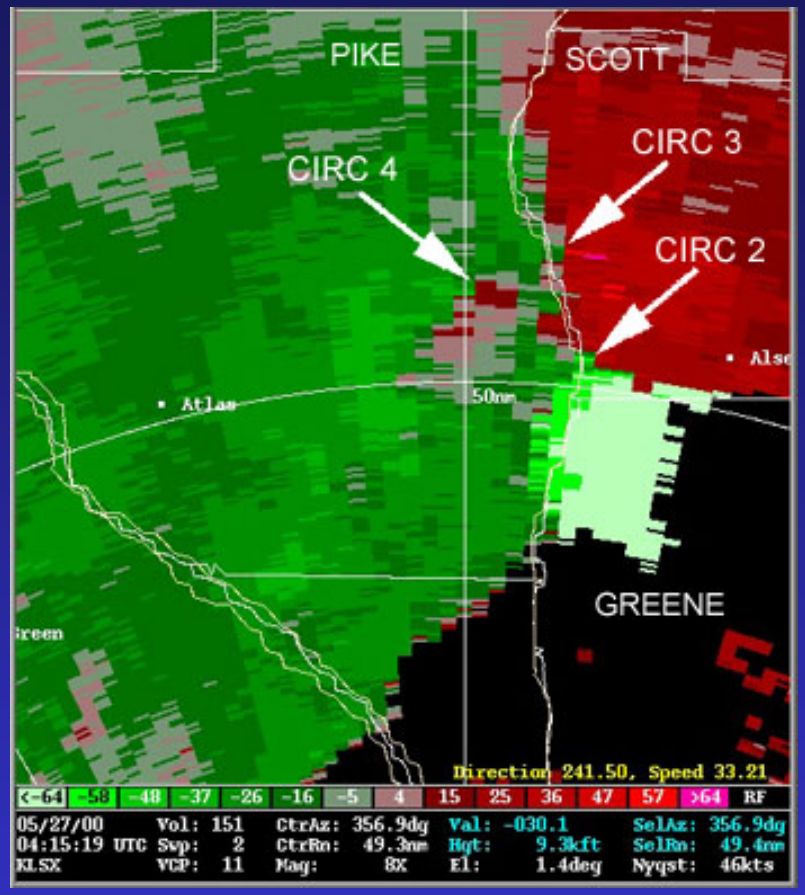




Same as preceding page except for TVS (TDA output).

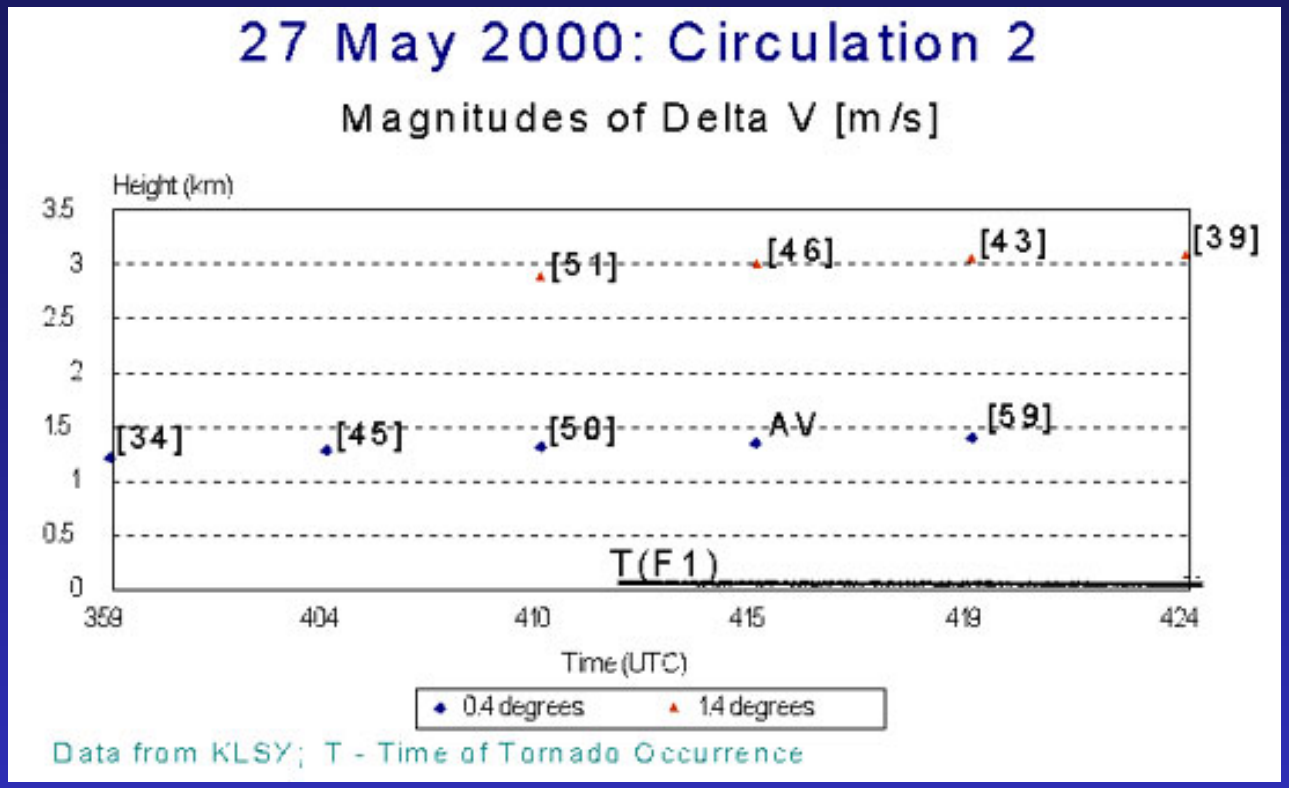
KLSX Reflectivity / SRM 0415 UTC / 1.5° slice





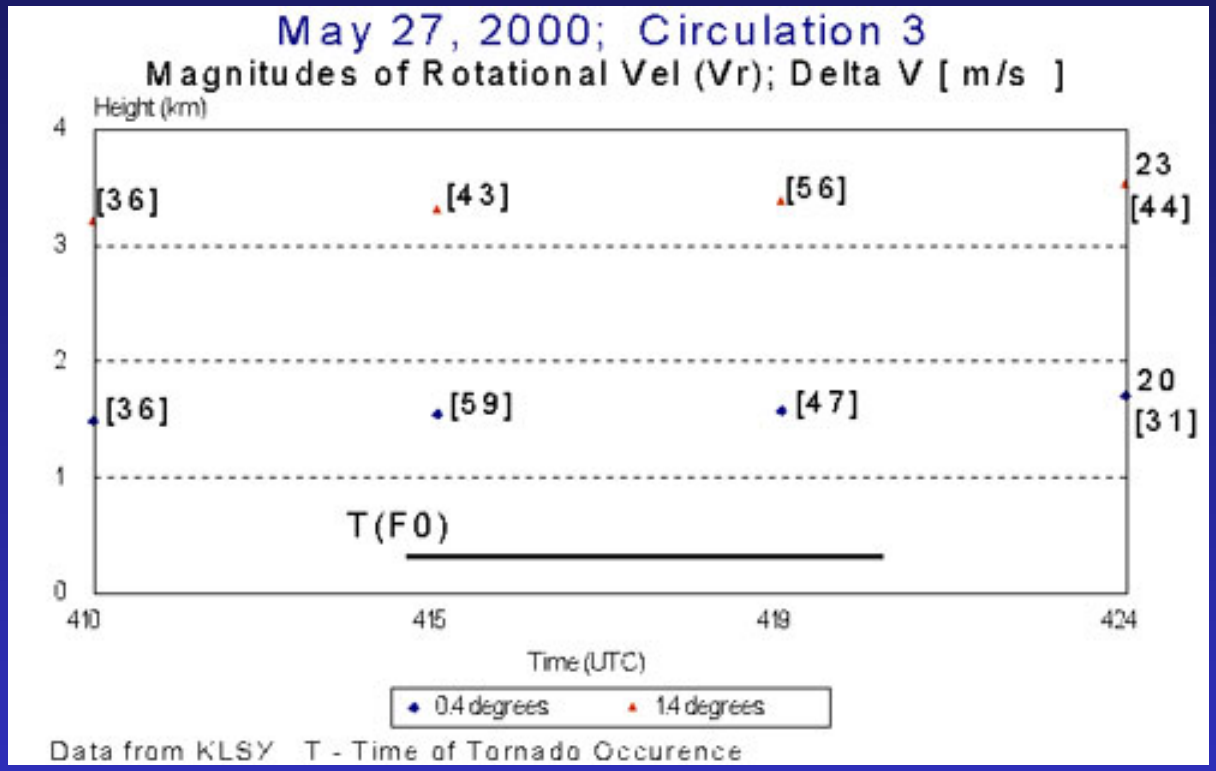
- Northern bowing segment remains well defined.
- Circ 2 remains a tornadocyclone (Delta V = 46 m s^{-1}).
- Circ 3 spawned a weak tornado at 0414 UTC (Delta V – 43 m s^{-1})
- Circ 4 formed in the vicinity of the developing comma-head.
- Nearly impossible to detect C2 and C3 in real time (core dia).

Time-height trace of magnitudes of Delta V

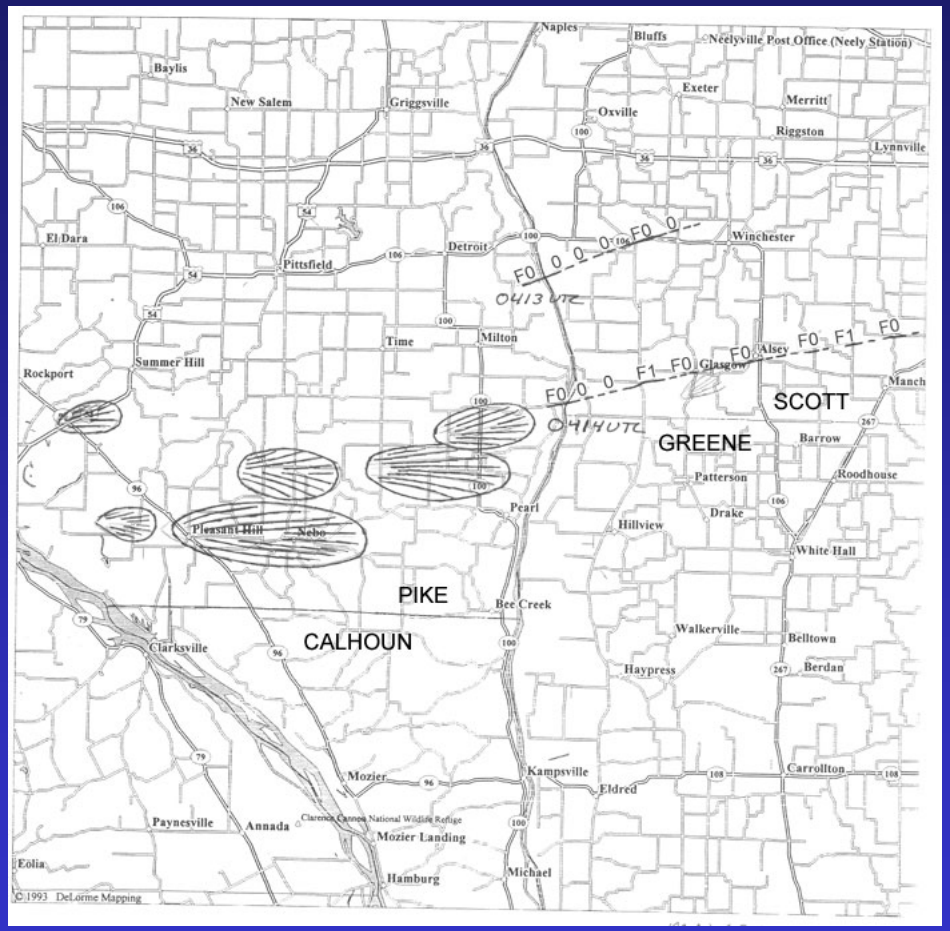


- Circ 2 initially formed at low-levels (below 2 km) then revealed *'non-descending'* characteristics.
- Gate-to-gate shears were detected throughout the circ's lifespan.
- Tornadogenesis occurred just after period of strongest gate-to-gate shears and vortex stretching.

Time-height trace of magnitudes of Delta-V



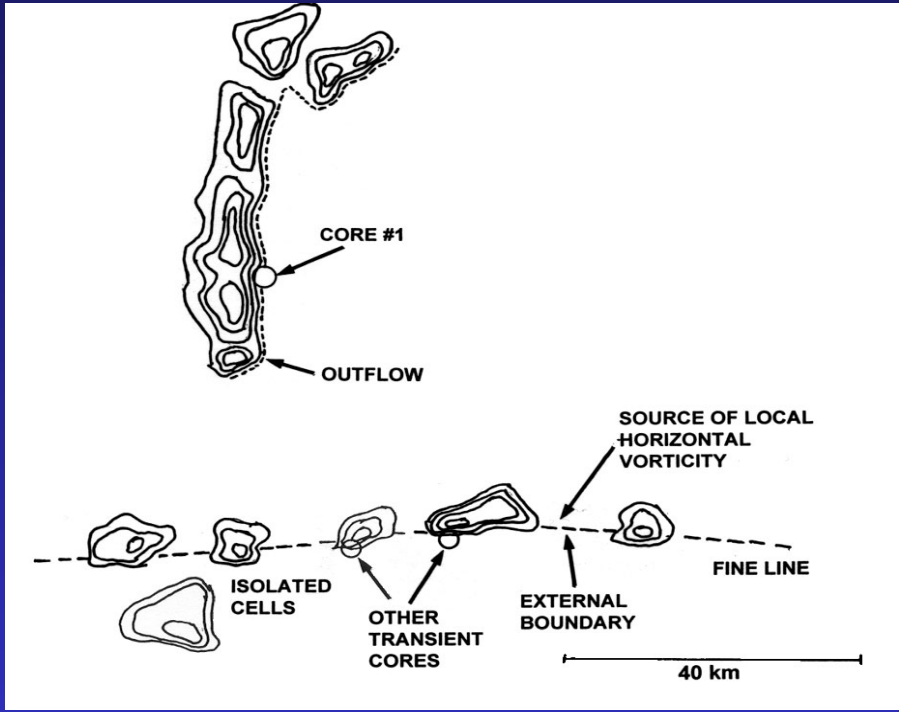
- Gate-to-Gate shears were detected throughout much of Circ's 3 lifespan.
- Tornadogenesis occurred near the time of strongest gate-to-gate shears (Delta-V – 59 m s^{-1} (0414 UTC)



Mapping of wind and tornadic damage tracks 26 – 27 May 2000.

3. *Low-level or (Quasi-stationary frontal) boundary located 20 – 150 km south of Convective Line*

- 5 cases
- 4 late night – early morning events
1 late afternoon – early evening.



a) Reflectivity characteristics
Convective line remains *north or northeast* of quasi-stationary frontal boundary (elevated convection).

- First reports of damaging winds often occur during the <u>*initial bowing*</u> of the line (***if convective-scale downdrafts are able to penetrate the cool stable layer north of the boundary).***

Group 3 cont'

- In **2** of the **5** events studied, the convective line was ***20 to 60 km north*** of the quasi-stationary frontal boundary.
- In the remaining **3 cases,** the convective line was well north ***(80 – 130 km)*** of the surface front ***(elevated convection).***

b. Depth of Stable Layer north of Boundary

- How do we measure the ***depth of the stable layer*** near the surface?

  First Approximations: **WSR-88D VWP data**
  Nearby Profiler sites
  LAPS Soundings
  Surface temperatures north of bndry.

- **3 of the 5 cases,** shallow stable layer was present (at or ***less than 0.5 km deep), widespread wind damage occurred.***
- In the remaining **2 cases,** the stable layer was ***greater than 2.5 km (5000 ft) deep. Only isolated wind damage occurred.***

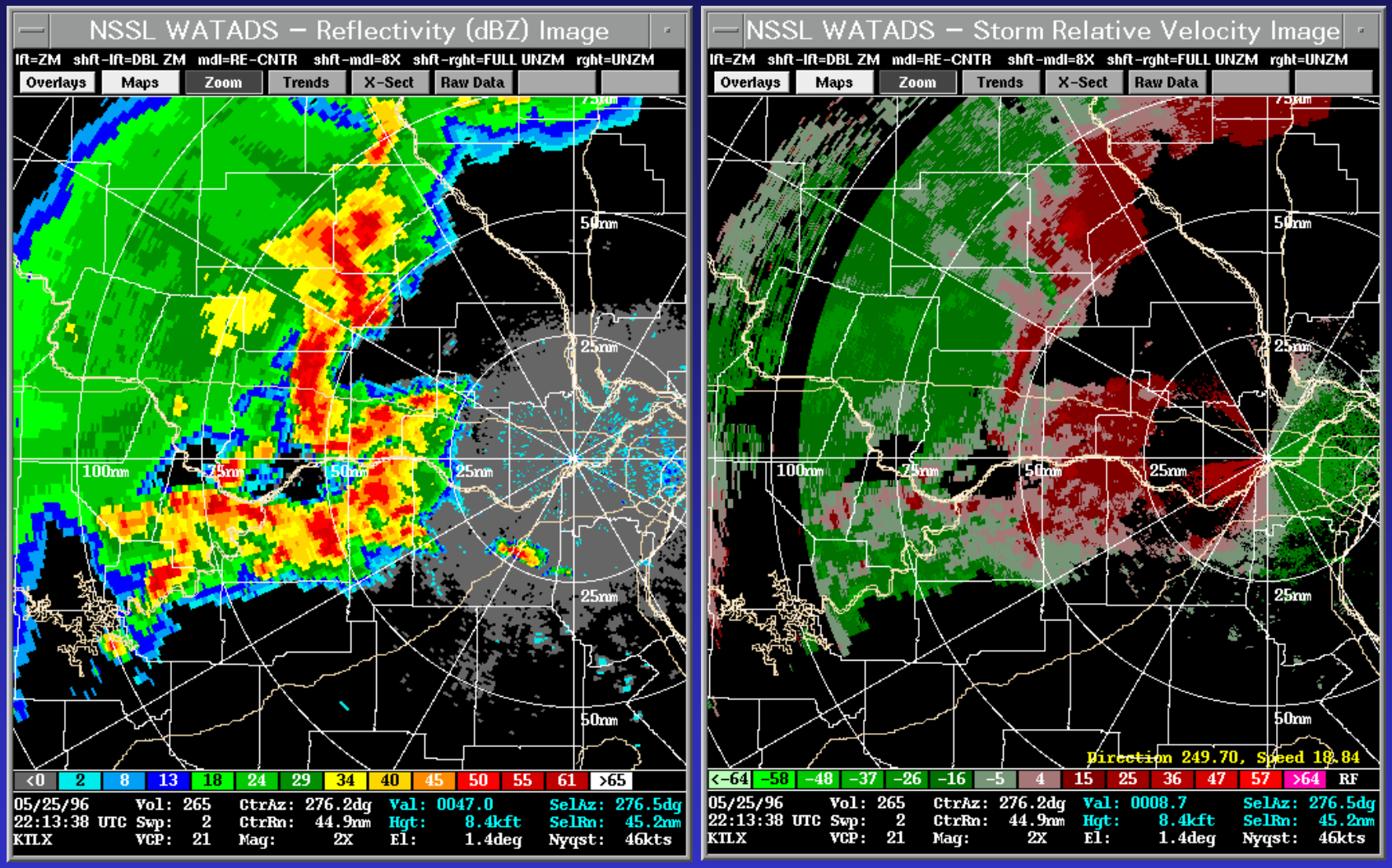
c) *Circulation Trends:*

- **Core #1 –** formed near the northern flank of the convective line
- **Core #2** ***and successive cores*** formed north of the apex of the bowing segment.

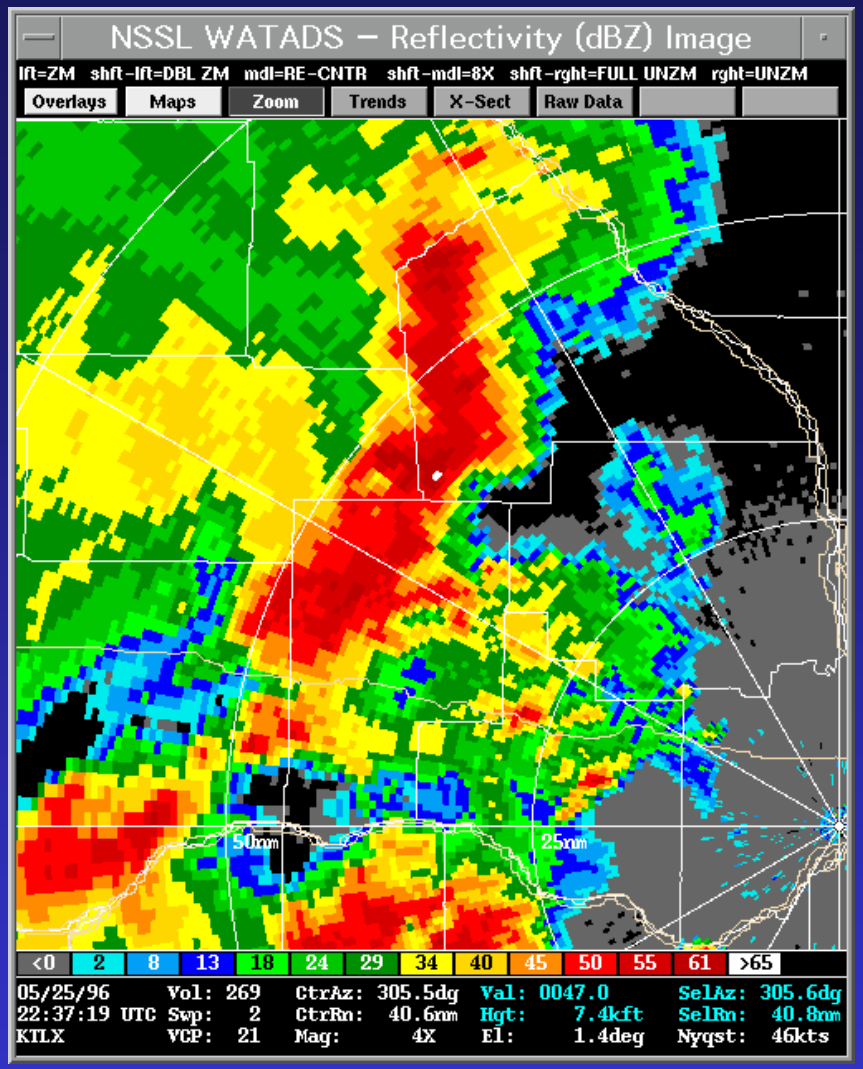
Core #2 – developed after isolated cell – convective line merger in **2 of the 5 cases** studied.

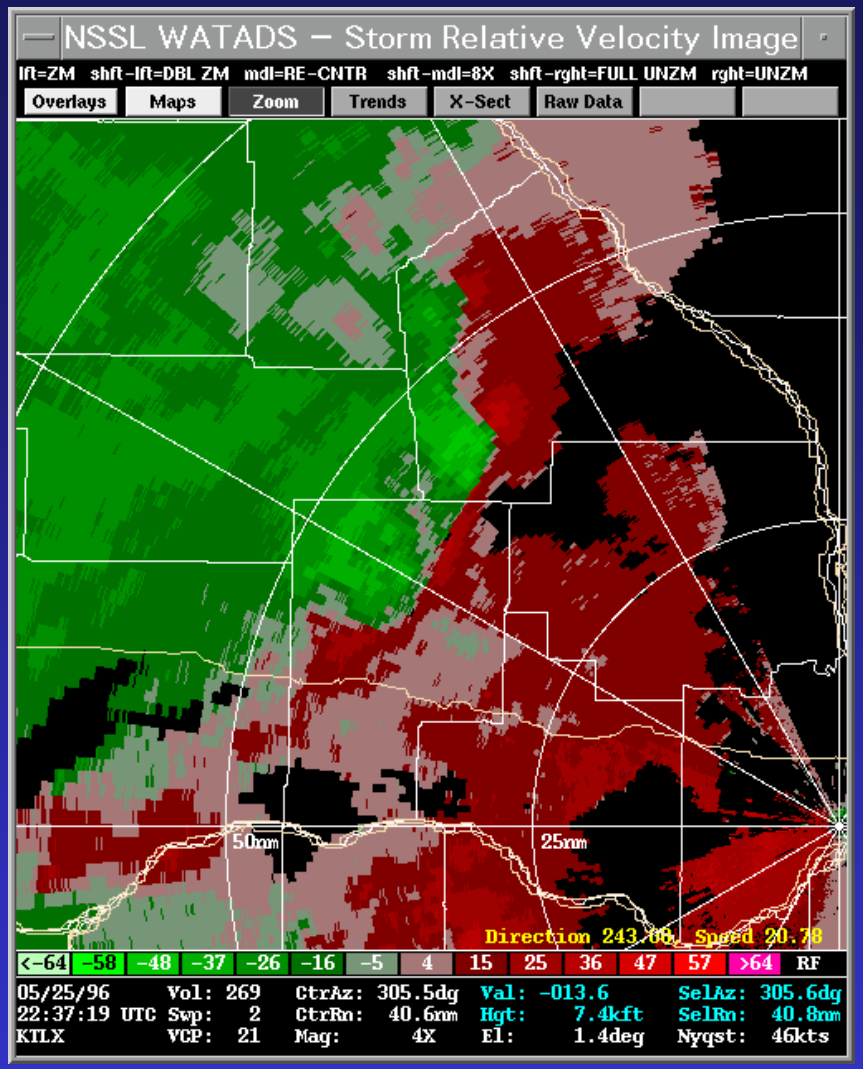
- **Core #1** originated at mid-levels. Exhibited weaker cyclonic shears compared to neighboring Cores 2 and 3.
- **Core #2** often revealed ***strongest rotation, greatest depth, longest lifetimes*** compared to neighboring mesocyclones. ***Non-descending*** characteristics was observed in **2** of the **5 cases.**
- **Core #2** in Group 3 cases were ***not as strong*** compared to second cores in Groups 1 and 2.

- **Tornadoes** were reported with **Core #2 in one of the five cases.**



2213 UTC 25 May 1996 reflectivity (0.5° slice)(left); storm-relative velocity (right), Circ #2 formed after isolated cell – convective line merger and intensified during the next 30 minutes. Transient vortices were identified with the convective cells along the old east-west frontal boundary.





2237 UTC 25 May 1996 reflectivity (1.5° slice)(left); storm-relative velocity (right). Circ #2 (40 nm NNW KLSX) spawned a tornado at 2242 UTC near the apex of the bowing segment.

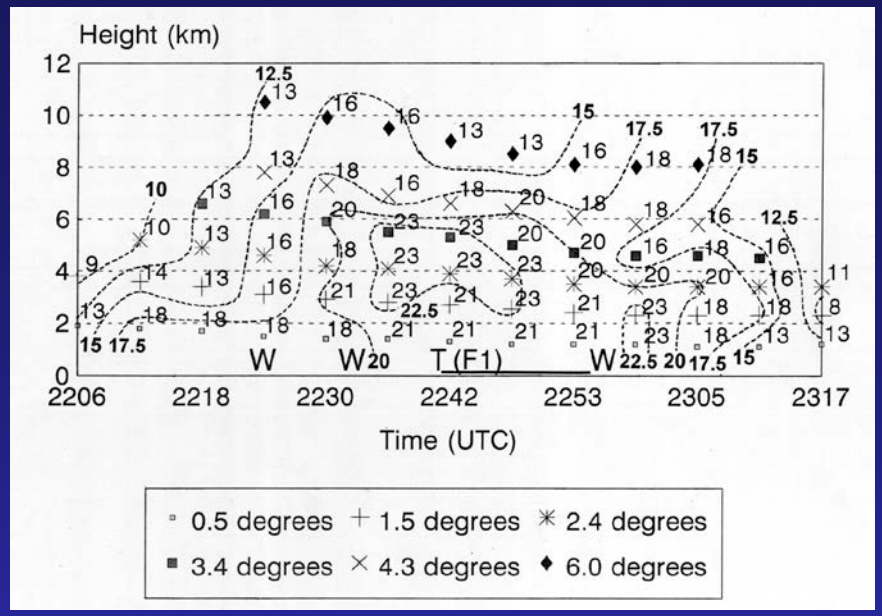
Comparison of Mesocyclone Cores #2 and #3 (25 May 96)

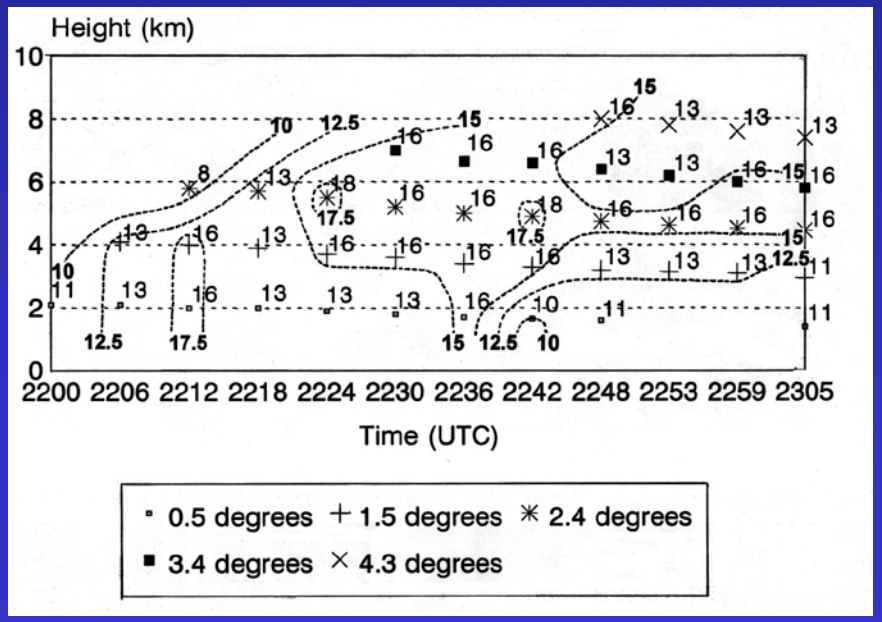
Cores #2 and #3 revealed upscale (*non-descending)* growth.

However, the low-level shears were weaker during the early stages compared to Core #2 in Groups 1 and 2.

Tornadic damage (F1) occurred well into the mature stages of Core #2.

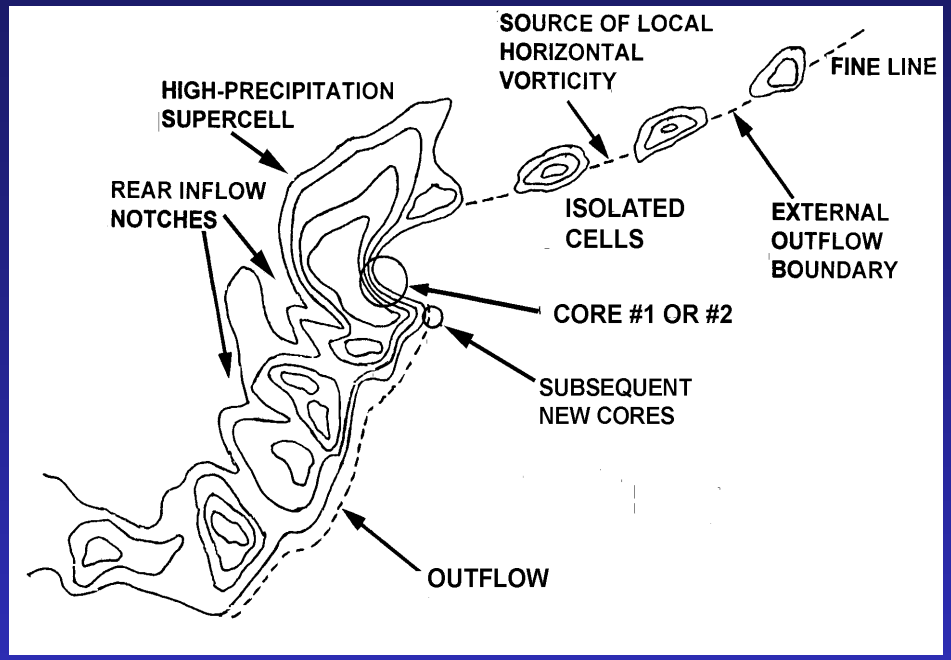
Severe weather was absent with Core #3.





4. *Low-level Boundary Intersecting the Forward Flank of a High-Precipitation supercell*

- 2 cases
1 late evening event
1 early afternoon



a) Reflectivity Characteristics

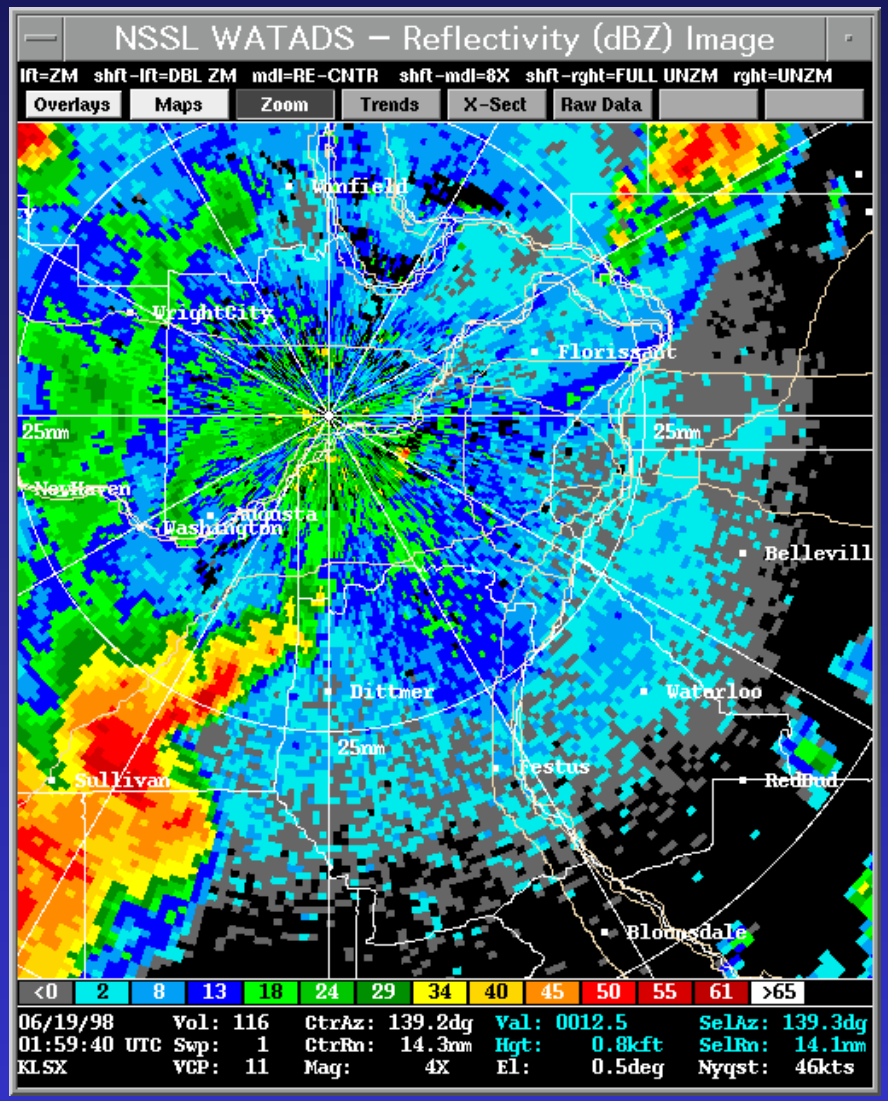
- HP storm evolves into a broad bowing line segment.
- Low-level boundary intersects the forward flank of an HP supercell.

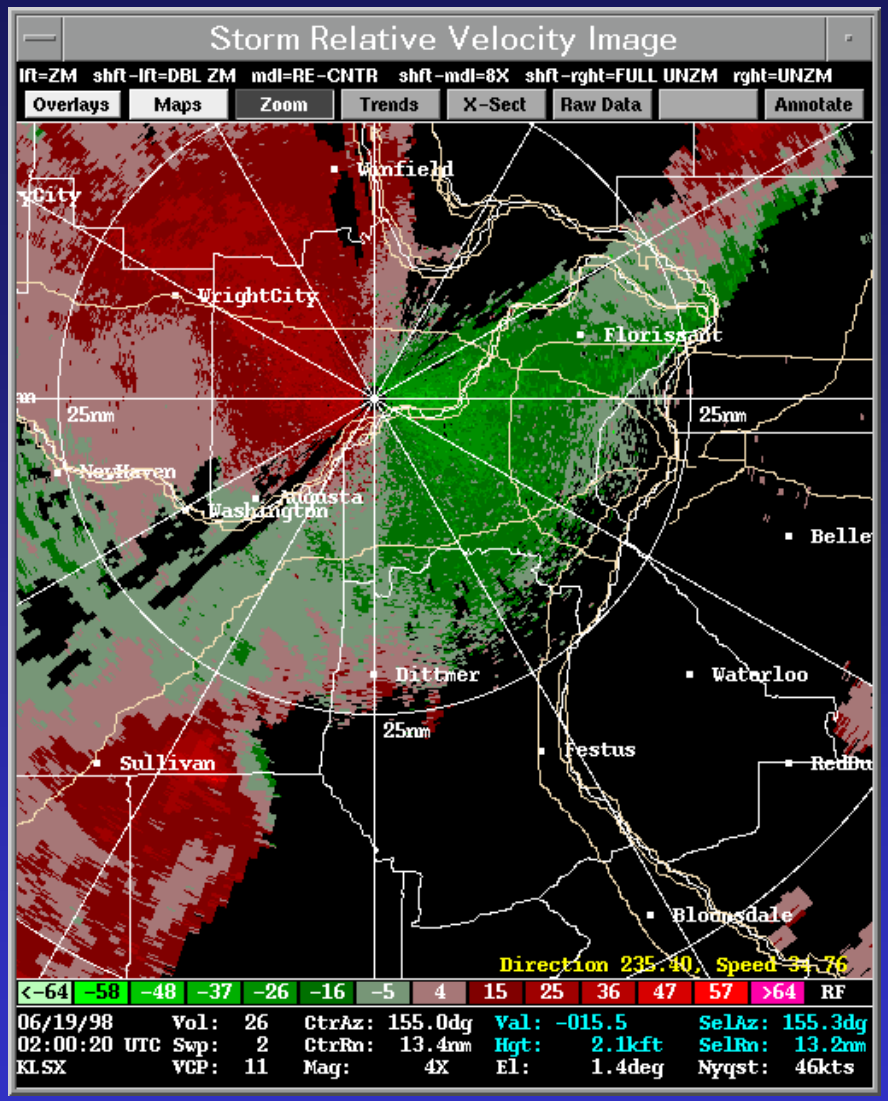
- First reports of damaging winds frequently occurs ***just south of the HP storm*** (along the leading edge of the HP storm's RFD).

b) *Circulation Trends*

- Single (or multiple) mesocyclone cores form within the **HP storm's *forward flank updraft.***

- **Core #1** originate from ***'mid-level beginnings'*** (similar to observations shown by Burgess et al. 1982 with classic supercells.
- **Core #1** may evolve into a ***'cyclonic divergent' (outflow dominated)*** circulation.
- **Second and successive cores** may form along the leading edge of the **HP storm's Rear Flank Downdraft.** These cores can become **tornadic.**



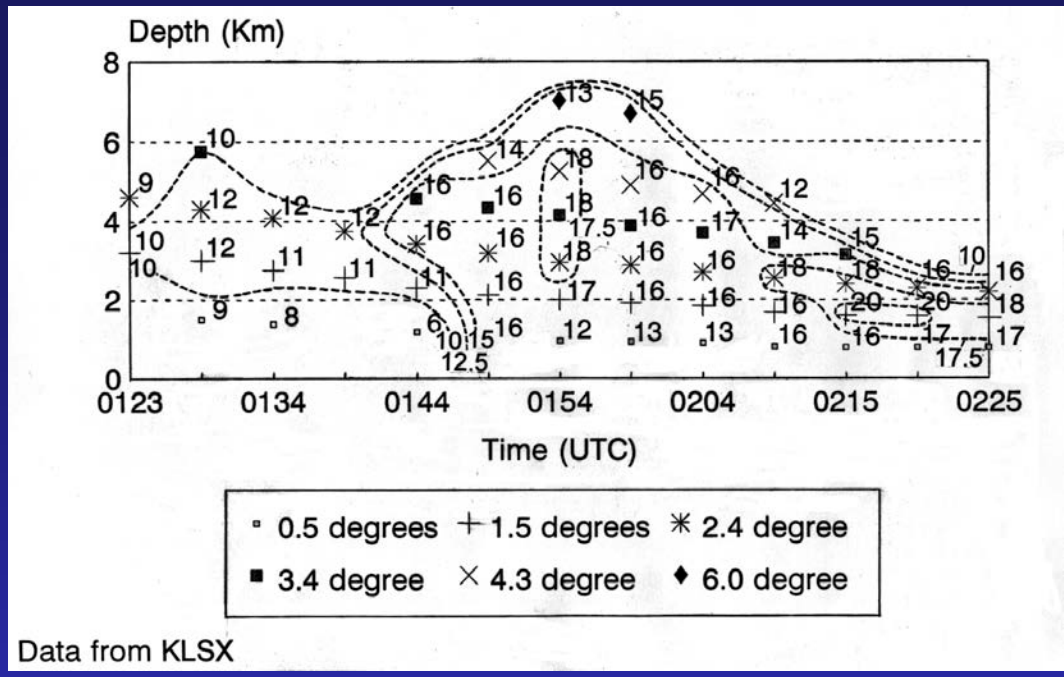


0159 UTC 19 June, 1998 plan view reflectivity (0.5° slice); storm-relative velocity (left) from KLSX.

June 18, 1998 case

- Circulation #1 originated from ***'mid-levels*** within the HP storm's ***forward flank.***

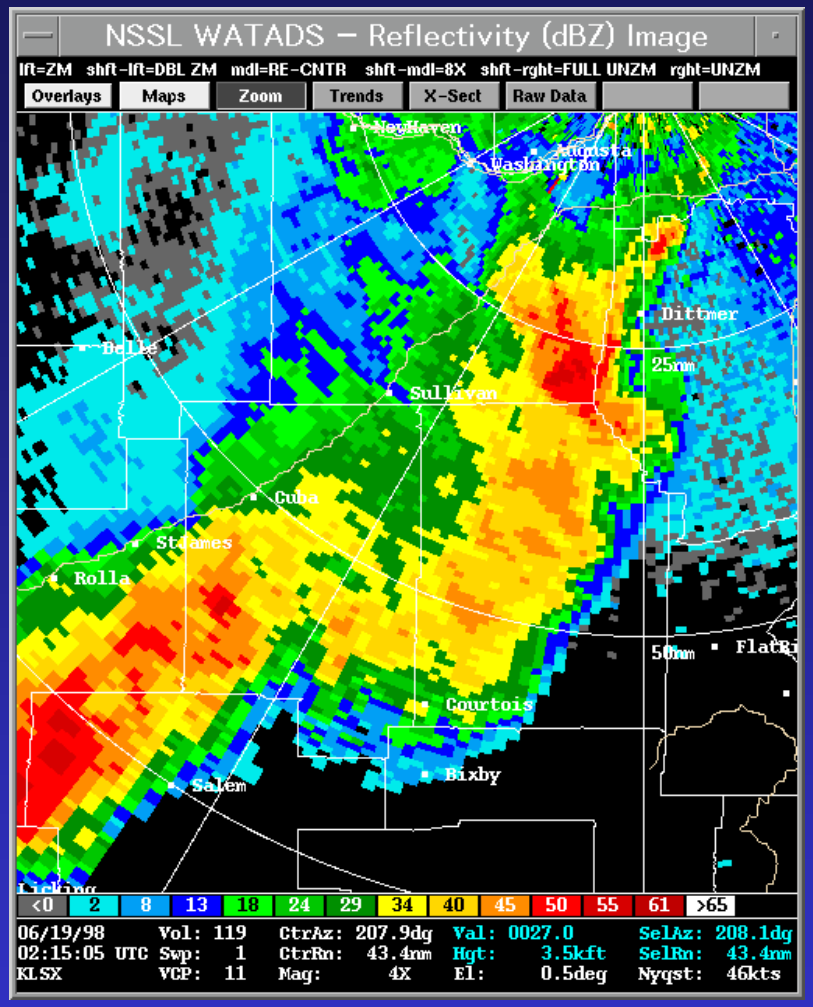
- After 0144 UTC **Circ #1** showed a period of growth (***upward and downward***) as it intensified ***(descending characteristics).***

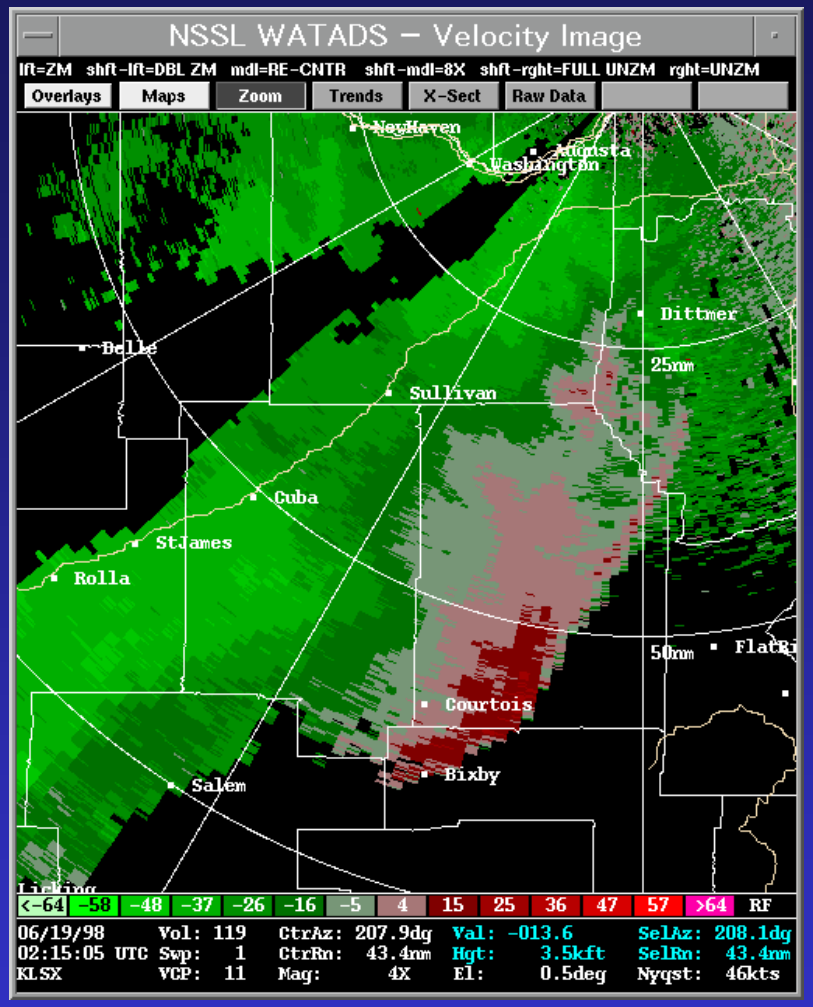


-After 0154 UTC, an ***unbalanced velocity couplet (cyclonic divergent)*** emerges.

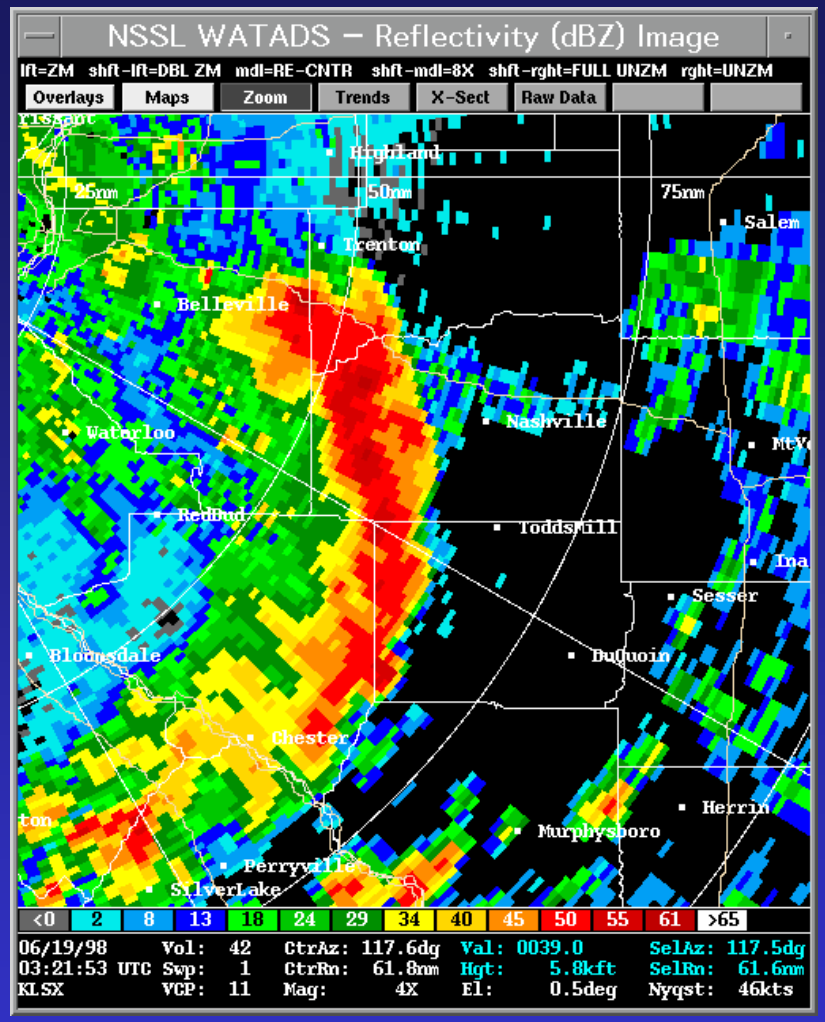
- Strongest rotation remains at ***mid-levels.***

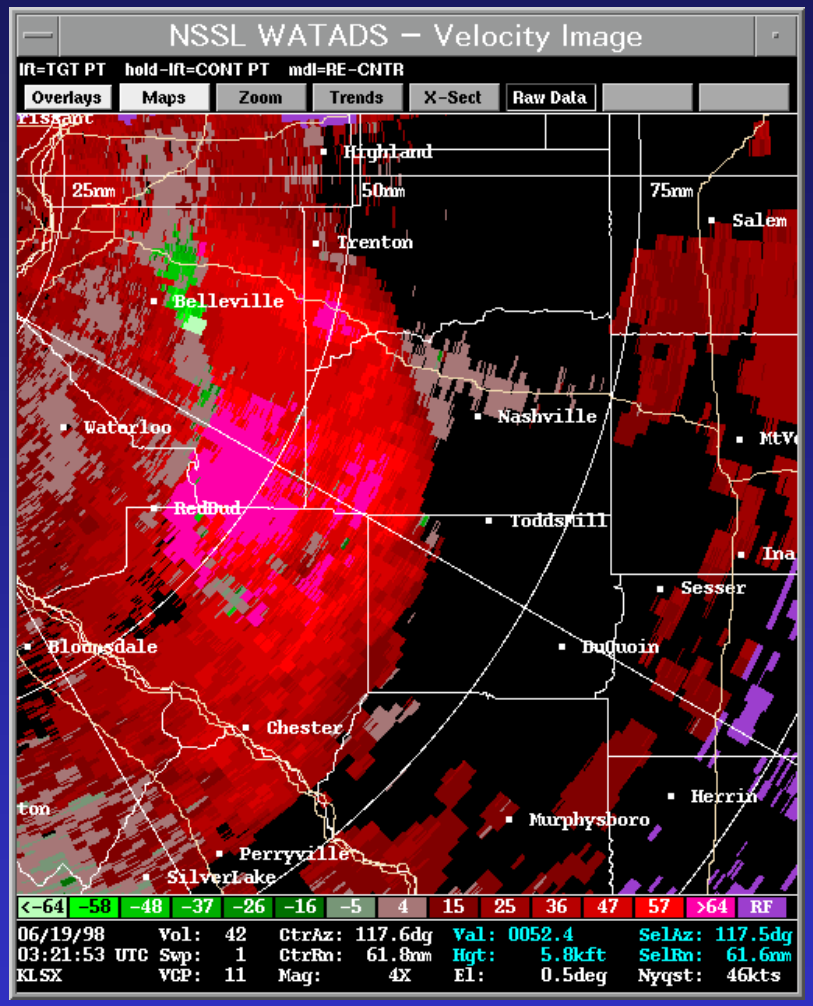
- Vr magnitudes once again ***intensify*** and ***lowers*** within the core after 0210 UTC.



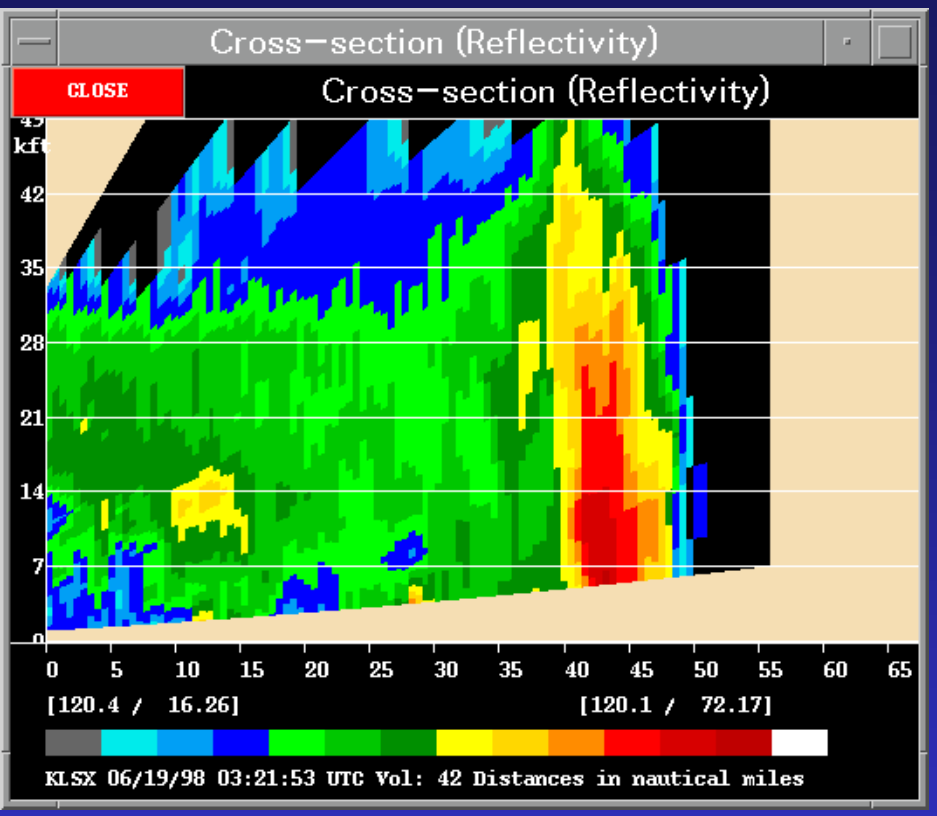


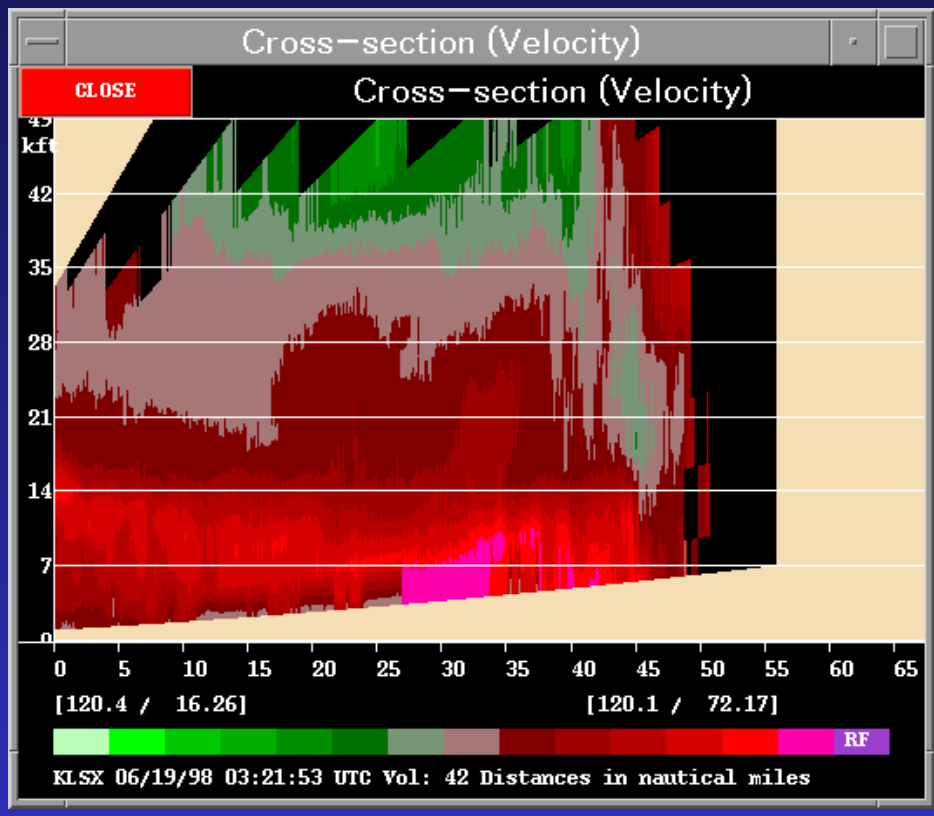
0215 UTC 19 June 1998 plan view reflectivity (0.5° slice) (left); storm-relative velocity (right).



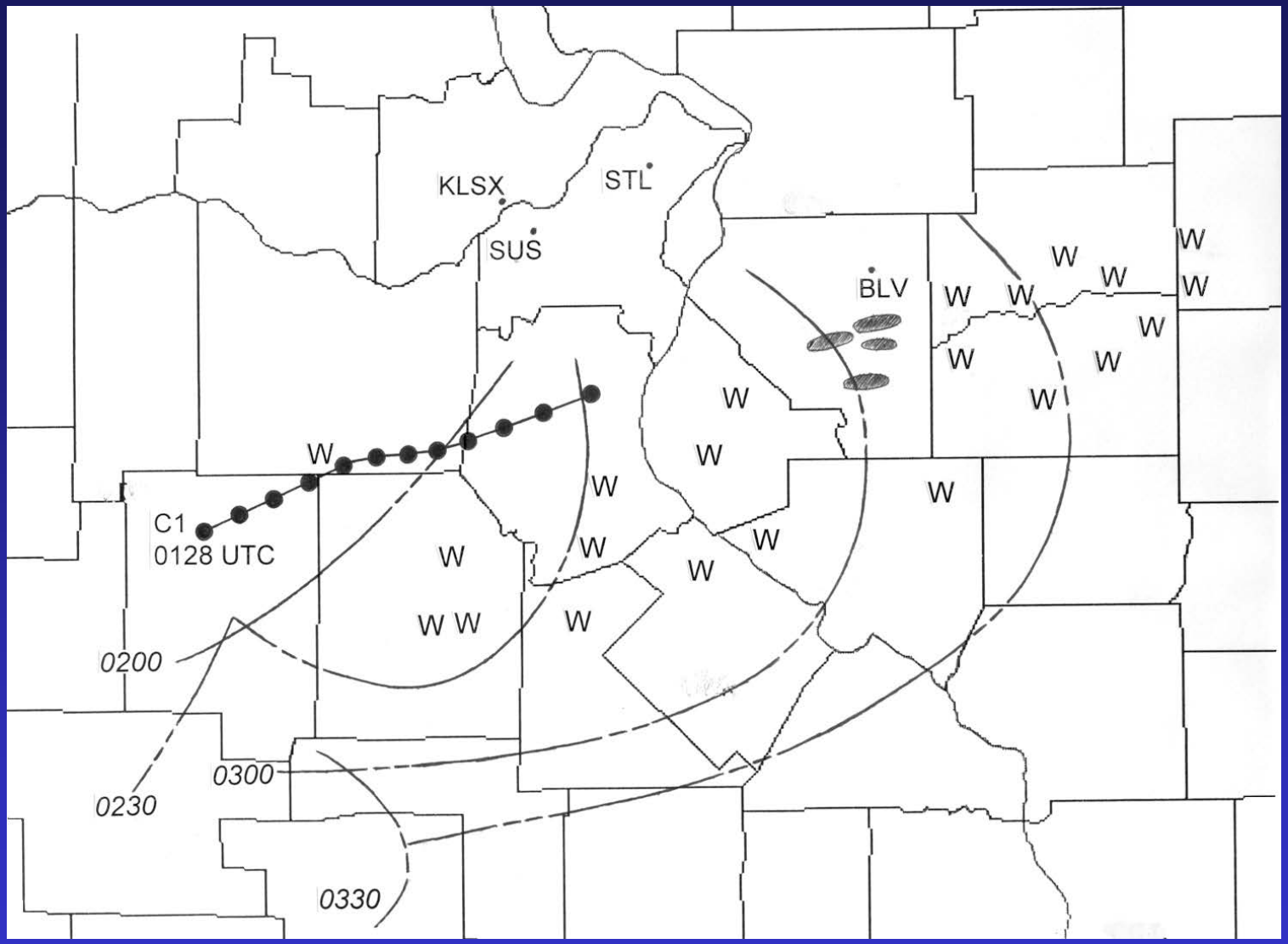


0321 UTC 19 June 1998 reflectivity (0.5° slice)(left); storm-relative velocity (right). Outbound velocities greater than 64 kts are noted across southern St. Clair – northern Randolph counties. Surface gusts over 80 mph were reported over southern St. Clair county.





0321 UTC 19 June 1998 reflectivity cross-section (left), storm relative velocity cross-section (right) taken at the 120° radial. The bright red region on the velocity cross-section represents a component of the mesoscale rear inflow.



Map of Circulation #1 track, squall line positions (every 30 minutes) and wind damage reports (W). Hatched region signifies swaths of intense wind damage. Nearly all of the wind damage occurred south and east of Circ #1's path.

(7) *Mesocyclone Characteristics*

Comparison of circulation characteristics between our data set and Burgess et al. (1982) data set.

	Rot Vel (m/s)	Diameter (km)	Height (km)
Squall Line (Low)	19.0	7.2	
Trad Super-cell (Low)	23.0	5.4	
Squall Line	18.8	7.4	7.6
Trad Supercell	25.0	6.0	9.2

L = surface to 8200 ft.

(8) *Summary*

- Twenty-four MCS events were studied across the Mid-Mississippi Valley Region during the period of late March – September 1992 – 2000.

- Our study focused on the ***'intensifying stage'*** of MCS evolution.

- The 21 MCSs were classified into four reflectivity patterns (or groups) with 13 of the 20 cases classified into **Groups 1** and **2.**

- In **Groups 1** and **2,** a low-level boundary intersected either the (***northern or southern part***) of the convective line.
- **Group 3** – convective line remains ***north*** of the outflow boundary or front. **Group 4** – HP storm – boundary intersection.

- **Groups 1** and **2: 1st** and **2nd core** mesocyclones formed near the intersection while **3rd *and successive cores*** formed north of the apex of the bowing segment.
    - **1st core** – weaker rotation compared to Core #2.
    - **2nd core** – strongest rotation, non-descending (***upscale growth***) and longest lifetime ***(Tornadic?)***
    - **3rd *and successive cores***

      3rd core – rotation just as strong as Core #2. Non-descending characteristics, shorter lifetime compared to **Core #2.** ***(Tornadic?).***

      Successive cores – rotation just as strong as Core # 3. Non-descending characteristics, even shorter lifetime compared to Core #3.

- ***Tornadoes*** frequently occur ***just prior to*** the mesocyclone core reaching its greatest depth and in the vicinity of strongest low-level rotation. '***Look for Trends'***

Summary cont'

Group 3 events

- Challenge we identified was determining the ***depth of the stable layer.*** Could severe downdrafts penetrate this stable layer north of an outflow boundary?
  - ***First approximations used:***
    1) time-height profiler data
    2) WSR-88D VWP data
    3) LAPS Sounding
    4) Surface temperature
- If the depth of the stable layer ***exceeded 5000 ft,*** then it was difficult for severe winds to penetrate the deep stable layer.

- **Circ #2** appeared to exhibit the strongest rotation, greatest depth and longest lifespan of the group of vortices detected. **One tornado** occurred in only one of the five cases.

Summary cont'

Group 4 events:

- **2 cases –** High Precipitation supercell evolved into a broad bowing structure.
- **HP storm's** updraft region (forward flank) intercepted an old outflow boundary in both cases.
- Several **tornadoes** occurred in first case. **Tornadoes** were absent in the second case. However, wind damage was extensive.
- **Mesocyclone cores (#1 and #2)** originated from ***Mid-level beginnings (4 – 7 km layer).*** In the first case, successive cores showed a non-descending characteristic and became tornadic.

Summary cont'

- **In Groups 1, 2 and 4: Core #2** appeared to have a secondary role where enhanced wind damage occurred along the southern periphery of the circulation's path.

Comparison of Mesocyclone characteristics with studies conducted by Burgess et al. 1982.

- Rotational strength – our **2nd cores** in **Groups 1 and 2** revealed weaker rotation, larger core diameters, and lower overall depths compared to supercell mesocyclones across Oklahoma.

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