1. QLCS storm-scale interrogation and warning considerations

Instructor Notes: Welcome to the AWOC Severe lesson on QLCS storm-scale interrogation and warning considerations. This lesson is 43 slides long and will probably take 45 minutes to take. Jim LaDue of WDTB and Ron Przybylinski, the SOO at NWS St. Louis, MO, will be your primary instructors.

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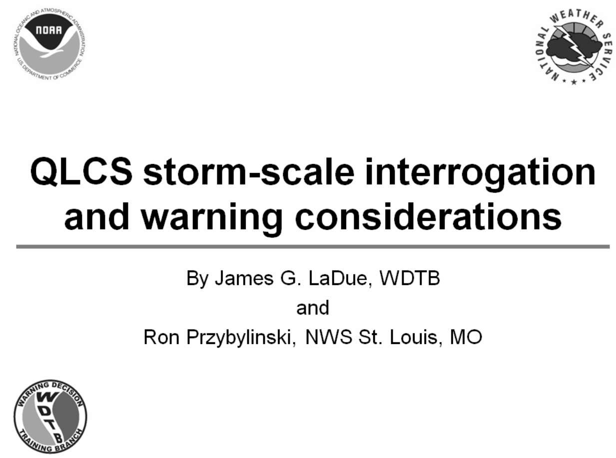

2. Objectives

Instructor Notes:

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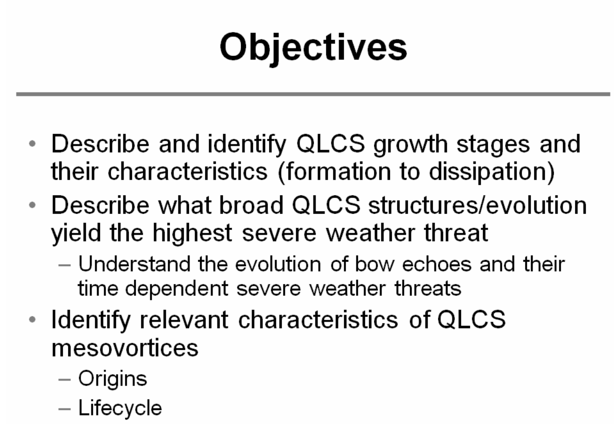

3. Objectives, contd

Instructor Notes:

Student Notes:

Objectives, contd

- Identify QLCS vortex severe wind/tornado precursor signatures
  - Location relative to the QLCS and rear inflow jet
  - Boundary intersections
  - Vortex width, base, height, strength
  - Evolution of precip features
- Understand warning decision making considerations for QLCS events.

4. Generic Lifecycle of a QLCS

Instructor Notes: This is to answer what stage in a QLCS lifecycle is most likely to produce most severe wind (tornado) potential. We typically evolve convective systems from a point where the updraft is primarily the dominant feature and the cold pool is yet too immature to interact with a the sheared environment. If we were in an environment where deep-layer shear is capable of supporting supercells and severe QLCS events, we would most likely see supercells in this case because the shear dominates the cold pool and the shear would interact primarily with the updrafts. We wouldn't expect to see QLCS-based mesovortices or cold pool-induced severe winds in this stage. As the original small multicells, whether clusters, or a line segment, merge and begin producing an enhanced cold pool, you finally have a period in which it becomes a significant contributor to the morphology of the updrafts. The lifting on the cold pool becomes more aggressive allowing for more widespread updraft formation, and the updraft tilt becomes as much a function of the cold pool as the environmental shear. There's a period in time where the cold pool balances well with the environmental shear allowing for deep, upright updrafts along the gust front. Lifting along the gust front forms the base of the updraft and the balance between the cold pool vorticity and the environmental shear forces that updraft to stand upright. If the shear continues through the deeper layer in the atmosphere, the updraft maintains its upright character and eventually overturns in both forward and backward trajectories forming the anvil. This is the tall echo stage of an impending severe QLCS event where the strongest MARC signatures prevail. Sometimes when bows form, they remain in the tall echo stage if the cold pool and shear remain balanced and deep convective overturning continues in the upper-levels. More likely the updraft depth decreases as the bow forms as the cold pool begins to race ahead. The more severe bows still maintain a deep gustfront with strong slab-like updraft from near surface to 20 kft AGL but then the updraft quickly tilts rearward. When you recognize the tall echo phase, you'd maximize your odds of verifying on a warning with adequate lead time. If the cold pool becomes too dominant, it begins to outrun the deep updraft leading to the gust front outrunning the deep convection. The updrafts often lose their slab-like lifting appearance and begin to breakup into a more cellular appearance. This kind of structure can appear along the edges of a bowing echo because in those areas, the cold pool dominates the shear. How is that possible? Well, it's really the component of the shear perpendicular to the gust front that's important and gust front bends back along the edges of a bow.

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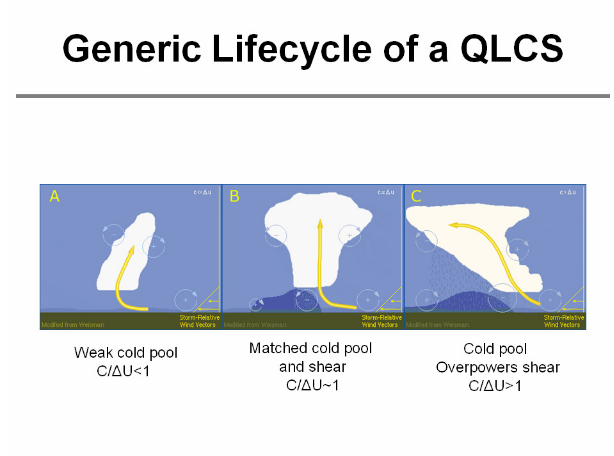
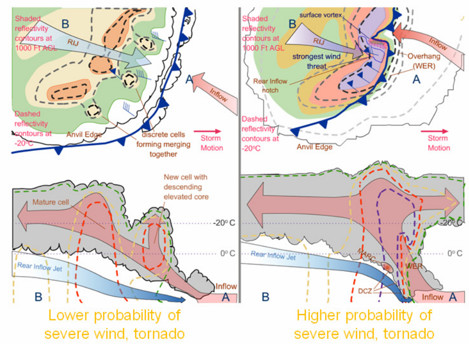


5. 3-D QLCS structure

Instructor Notes: The most severe QLCS events typically have and upright updraft with almost slab-like appearance along a deep gust front. The convection is able to remain attached to the gust front and so on radar, you may not actually see a separate fine line from the intense reflectivity cores. A deep convergent zone accompanies the gust front. On some occasions, and after accounting for system motion during volume scanning, you may see a strong echo overhang leading the reflectivity core. Rear inflow notches signify intense RIJ channels. The RIJ remains elevated to descend only immediately behind the convective line. Lightning often precedes the arrival of the line. Mesovortices are common with these structures as there is plenty of deep updraft over their formation regions. The less severe events exhibit more isolated convective cells often displaced well behind the gust front. A separate fineline is often visible ahead of the first reflectivity cores. The gust front is often severely sloped with a shallow leading edge. The RIJ often descends well behind the leading convective cores. Deep, severe mesovortices would be extremely rare with a sloped system like this.

Student Notes:

3-D QLCS structure

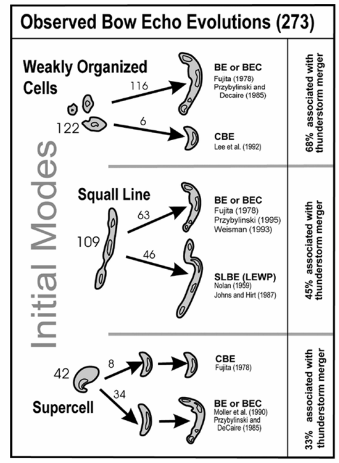


6. Initial convective modes leading to Bow Echoes

Instructor Notes: By the time you see the reflectivity echo of a multicell organize into a bow, it's already too late to issue a warning because the strong outflow has already been on the ground long enough to deform the precipitation shield. So it's useful to understand what kinds of convective structures lead to damaging bows. Here's a study by Klimowski, Hjelmfelt, and Bunkers in 2004 where hundreds of damaging bows were backtracked in time to see what created them. The most common evolution was the merger of small weakly organized multicells that were originally noninteracting. However, they quickly started interacting when one of the individual small multicells merged with another setting off a sequence of rapid cold pool production and subsequent bow. The fastest of the individual small cells or multicells usually corresponded to the motion of the bow. Sometimes the individual small multicells would briefly organize into a line on its way to a bow. Either way, the consolidation of individual cells likely helped create a similar consolidation of cold pools and helped to contribute to intense updraft and subsequent downdraft formation. The second most common evolution of a bow came from a squall line that persisted more than the pre-bow linear structures that we just talked about. In this type of evolution, the squall line is moving east changing relatively little in structure and then a trigger causes a forward surge in the gust front in a confined segment. Most often the trigger is an interaction with a pre-existing boundary or another convective storm. Sometimes the trigger is more subtle and may be manifested as a significant updraft surge somewhere along the line. By the way, the acronym of BE is defined as a classic bow echo whereas BEC is a Bow Echo Complex. The latter is when a bow echo is the primary, but not the only convective structure making up a multicell. The former is when the multicell is completely identified as a bow echo. Finally, a bow echo accompanying others along a line is called a Squall Line Bow Echo (SLBE), and has been also called a Line Echo Wave Pattern (LEWP). The third kind of bow echo evolves from a supercell when the bowing rear flank downdraft ignites strong convection along its gust front, and the mesocyclone begins to morph into a line end vortex, or QLCS vortex. Bow echoes originating from squall lines tended to have the longest lifespan (3.4 hr) vs. 2.9 hr from initial clusters. Bows originating from squall lines seem to be most common in the eastern US.

Student Notes:

Initial convective modes leading to Bow Echoes

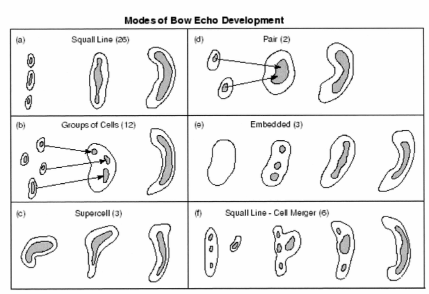


7. Initial convective modes leading to Bow Echoes – cool season

Instructor Notes: Another study by Burke and Schultz also investigated what kinds of convection led to bows, but only for cool season events. They're classification scheme added three new categories including an embedded line development, pairs of cells, and a squall line-cell merger. Like Klimowski et al., most of the bows originated as a linear squall line or a group of isolated cells. They also noted that merging cells or small multi-cells occurred frequently before bow echo genesis. For the cool season, supercells occurred in 43% of the formative and mature stages of bow echoes and 38% of squall-lines had supercells embedded. Nine of their 51 cool season cases were termed long-lived bow echoes (LBE's) that qualified as Derechos too. The number of cases for each storm type are listed in parentheses.

Student Notes:

Initial convective modes leading to Bow Echoes – cool season



8. Initial stage of a damaging bow echo

Instructor Notes: The initial stage of a bow echo at the onset of severe damaging surface winds is a time when the precipitation area is not bowed at all. An updraft surge typically happens which then yields a severe downdraft. Also at the same time, anvil debris typically spreads rearward of the main convective line with respect to the steering layer flow. This anvil debris acts to initiate the rear inflow jet (RIJ). Assuming you're about to have a severe bow echo, the best time for initial warnings is in the tall echo state when updraft surges occur prior to the onset of the severe downdraft and RIJ. This is when you typically see strong, deep convergence, represented by the MARC (Mid Altitude Radial Convergence), along a segment of the line. Just before the bowing state, the descending RIJ hits the ground and begins to push forward. The most severe mesovortices may form at this time. The most severe surface winds occur when the mesovortex forms near the apex of the RIJ. As the convection morphs into a bow echo, the updraft depth often decreases, and a rear to front dry slot forms. The strong outflow from the RIJ is firmly established and has been on the ground for some time.

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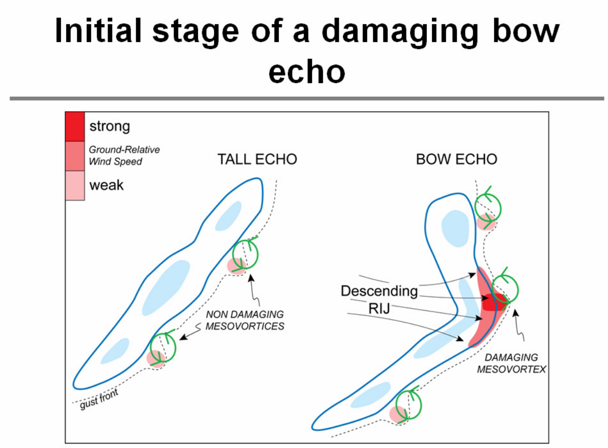
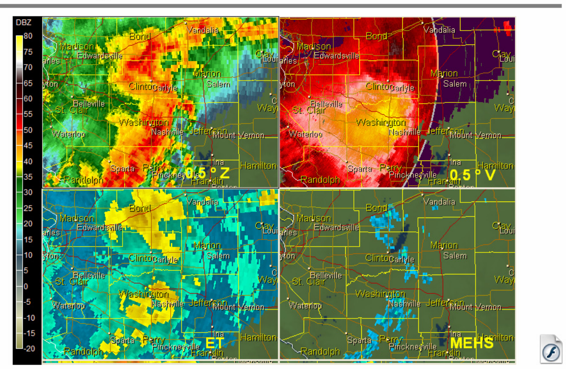


9. An example of a bow echo lifecycle: 10 June 2003 - STL

Instructor Notes: A flash-based looper will popup in a separate window in 10 seconds but first direct your attention to this main articulate slide. I'll wait until you get your bearings. This case of a bow forming shows the first cells at a very updraft-dominant stage. This is the time in which you first see the upscale organization of small multicells slowly consolidate and merge. If the shear is strong enough, then some of these small multicells may be supercells. Echo tops are usually high and the updrafts are deep. Notice the relatively high values of maximum expected hail size (MEHS). Next, the small multicells consolidate and new, strong updrafts begin to produce strong downdrafts. You can see the outflow already surging toward the radar. This is a time when the first warnings would've been out if you deem this event potentially severe, as in this case. In the next image, this QLCS is still exhibiting tall reflectivity echoes, a sign of deep updrafts. However the RIJ is strong, and there have already been several severe mesovortices to the left of small surges of the gust front that have produced tornadoes and enhanced severe winds. The main precipitation shield has not yet deformed into the classic bow shape but it is about to produce the most severe winds yet. In this image there is the most faint hint of a rear inflow dry notch impinging inward from the west over Belleville, IL. This notch represents the most intense RIJ along this QLCS. The strongest mesovortex of this event forms to the north of the RIJ axis and that is where the most intense wind damage was observed along a belt northeast of Belleville to across the Mid America airport and Scott AFB and then southwest of Clinton, IL. It's clear there's a better association of the intense winds with the mesovortex, and not so much the RIJ axis. The last frame in this loop now shows a classic bow echo appearance though only well after the onset of the most damaging winds and most of the QLCS tornadoes. The echo tops have gone down as well as the MEHS, all indicating a trend toward shallower updrafts. The leading edge of the deep convection is still keeping up with the gust front and this bow echo is still more than just borderline severe. In the flash window loop, step through the frames to see the full evolution. Overlaid on the velocity panel, you'll see a box containing a detailed graphic of wind damage and tornadoes. The white shaded regions show wind damage of F0 (EF0) or greater while the white lines represent tornadoes. The small checkbox brings up the most relevant graphical conceptual model that corresponds to the stage of the QLCS in its lifecycle.

Student Notes:

An example of a bow echo lifecycle: 10 June 2003 - STL



10. Early lifecycle of 4 Jul, 2004 Springfield, MO event

Instructor Notes: This event is an example of a bow echo originating from a multicell cluster. However, you could classify this evolution as an initial squall line since each multicell cluster was aligned on a common gust front. A popup window will appear with Ron Przybylinski, the SOO at WFO St. Louis, discussing the evolution of this severe bow echo from its inception. Ron has written and spoken extensively about QLCS severe weather events. Grab a drink and enjoy Ron's tour of this bow echo evolution. Ron's captions: Looking at reflectivity and storm-relative velocity from 10:02 - 10:24 - 10:37 UTC, you'll find that there was a weak vortex, not really well defined. You may come across weak circulations during this initial isolated, to cluster phase of a bow echo. Nolan Atkins has documented these events back during BAMEX where we observed weak and short-lived vortices. Now we move forward to 1041 UTC we don't see much rotation but we do see inbounds behind on the backside of this cluster of storms. This is the tall echo stage. We start seeing some cyclonic shear in the midlevels. Mostly hail and high winds can be expected here around 1107 UTC. Moving forward, we see a vortex, now at the leading edge! We mentioned this particular vortex showing up around 11 UTC but now it's showing up nicely. Now the SRM data is showing a vortex in Cherokee county. We move closer in time (to the first tornado) and we see a multiple vortex structure. One to the southwest of Joplin and one to the northwest. It was this second vortex that spawned a tornado in northern Newton county. Note the location of the surface boundary (connecting with the tornadic vortex). We've seen this play a role with many QLCS tornadic events. Going back to reflectivity, we see a nice bowing structure with a rear inflow notch forming (at tornado time). We see multiple rear inflow notches where some lower Theta-E air penetrates into the leading convective line. Going back to SRM data, there's additional wind damage along the apex of the bow and the RIJ but to the south of the tornado. The damage was not so bad north of the tornadic vortex. Most of the wind damage was south and east across Neosho and counties directly downstream of the bow echo.

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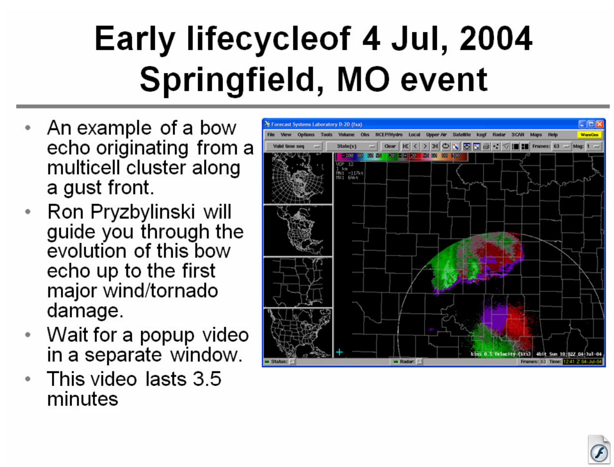


11. Review of the 04 July 2004 evolution

Instructor Notes: The bow started as a multicell cluster on a gust front (a cross between the cluster and squall line origins in Klimowski et al. 2004 and Burke and Schultz, 2004) QLCS vortices were weak in the early stages before the RIJ formed QLCS vortices strengthened here after signatures of the RIJ form (rear inflow notch, inbounds) The leading boundary intersecting the bow was associated with a tornadic mesovortex. The most wind damage was along and north of the RIJ axis to the tornadic mesovortex.

Student Notes:

Review of the 04 July 2004 evolution

- The bow started as a multicell cluster on a gust front
  - (a cross between the cluster and squall line origins in Klimowski et al. 2004 and Burke and Schultz, 2004)
- QLCS vortices were weak in the early stages before the RIJ forms
- QLCS vortices strengthened after signatures of the RIJ formed
  - (rear inflow notch, inbounds)
- The leading boundary intersecting the bow was associated with a tornadic mesovortex.
- The most wind damage was along and north of the RIJ axis to the tornadic mesovortex.

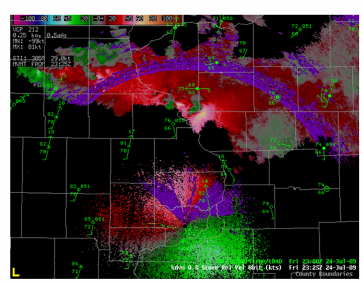
12. Early lifecycle of the 24 July, 2009 DVN QLCS

Instructor Notes: In this case, the bow echo starts off as two interacting supercells. Ron Przybylinski guides you through the evolution. Wait for the popup window and the video lasts two minutes. From Ron's captions: Another form of convective line evolution formed from supercell structures in the Davenport CWA. In this case, there are two supercells with strong mesocyclones positioned east-west. With time, these two supercells weaken in terms of their reflectivity structure though but the eastern one still has strong inflow notch. SRM data doesn't show much but some weak rotation on the eastern storm (near Scales Mound) and another is trying to form with the same storm at the head of the RFD push. As the storms continue moving southeast, and we see the bowing segment (especially with the RFD push) continue to evolve. The bowing segment continues to evolve and become dominant into Carroll county. SRM shows some weak rotation but nothing substantial at this time. Continuing further southeast and the main bow continues while a second bowing segment forms to the west.

Student Notes:

Early lifecycle of the 24 July , 2009 DVN QLCS

- Now here's a bow echo originating from supercells.
- Ron Pryzbylinski will guide you through the early evolution of this bow.
- Wait for a popup video in a separate window.
- This video lasts 2 minutes



13. Review of the 24 July 2009 evolution

Instructor Notes: Two supercells exhibited HP characteristics, each with significant low-level mesocyclones The RFD of the eastern one erupted convection. Given the shape of the RFD gust front, the convection acquired a bow shape with an enhanced RIJ that was the RFD. Many times the primary mesocyclone occludes and drifts rearward

Student Notes:

Review of the 24 July 2009 evolution

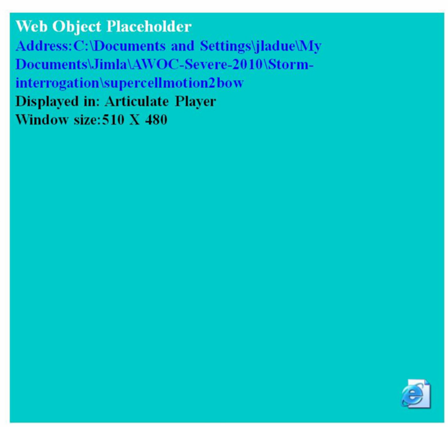
- Two HP supercells, with low-level mesocyclones
- The RFD of the eastern one erupted convection.
- New convection acquired a bow shape with an enhanced RIJ that was the RFD.
- Many times the primary mesocyclone occludes and drifts rearward

14. Supercell to bow echo motion

Instructor Notes: Watch the evolution of this supercell to bow echo as I move this loop using the feature following zoom following the supercell. As the supercells go on, you can see they're moving relatively closely to how I placed my 'drag me to storm' feature. As the supercell turns into a bow echo, you can see that the motion starts moving off to the left (of the distance speed tool). Now I'll move it faster so you can see the evolution in a different way.

Student Notes:

Change in storm motion from supercell to bow echo



15. QLCS-storm-interrogation-Quiz1

Instructor Notes:

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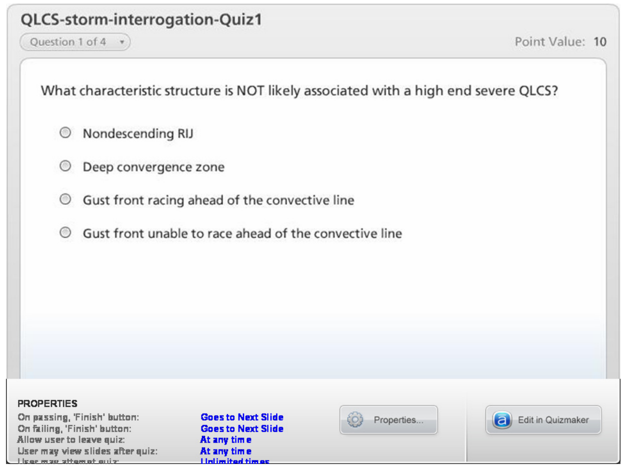

16. QLCS Mesovortex structure, evolution

Instructor Notes: While both the supercell mesocyclone and the QLCS mesovortex exhibit vertical vorticity at least partly colocated with updraft, they are structurally and dynamically different animals. You can see the differences with these two examples. At low-levels, the supercell features an obvious hook echo and broad, concave notch with a sharp reflectivity gradient. There is an occluding low-level mesocyclone, and enhanced inbounds further east signifying strong inflow into the RFD gust front indicating a new mesocyclone may be underway. The QLCS at low-levels shows a less obvious inflow notch and sometimes a rear inflow notch. The mesovortex forms along the gust front, and in this case, that's on the leading edge. At midlevels (15kft AGL), the supercell notch, or WER is closing off into a BWER while the inflow notch on the QLCS is less obvious. There are even more stark differences in SRM. Now you can see the occluded low-level mesocyclone is deep. The new mesocyclone is strongest at this level. Meanwhile, the QLCS mesovortex does not reach this level. The radar is sampling at the top of the gust front. Let me discuss a couple things you should know. First, the terminology, mesocyclone and mesovortex can be somewhat confusing. After all they are both mesovortices. These terms came about from different paths and often there is little coordination or reassessment to see if there would be ensuing confusion amongst the research community. So often it's useful to say supercell mesocyclone or QLCS mesovortex if this helps you to categorize their differing behaviors. Also, there is a term called bookend vortex. The mesovortex, such as this one, is not the kind of vortex that researchers from back to the days of Fujita called a bookend vortex. The bookend vortex refers to the circulation associated with the bow echo comma head and is quite a bit larger than a typical mesovortex. Sometimes mesovortices grow upscale to become bookend vortices.

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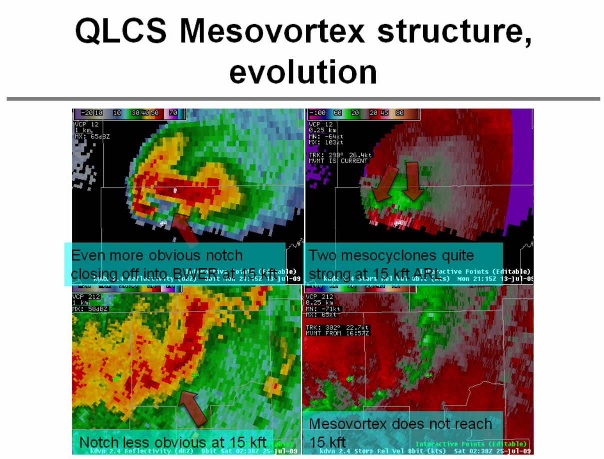

17. QLCS mesovortex structure and evolution: tracks

Instructor Notes: We'll take a closer look at the northern bowing segment for the June 10 case. Notice that the most intense mesovortices form well after the convective echoes congeal together to form a QLCS. We'll take a look at the initiation and evolution of mesovortex #6. If you'd like, please take a look at this case study written up by Atkins et al. 2005 titled "Damaging surface wind mechanism within the 10 June 2003 Saint Louis bow echo during BAMEX" in Monthly Weather Review.

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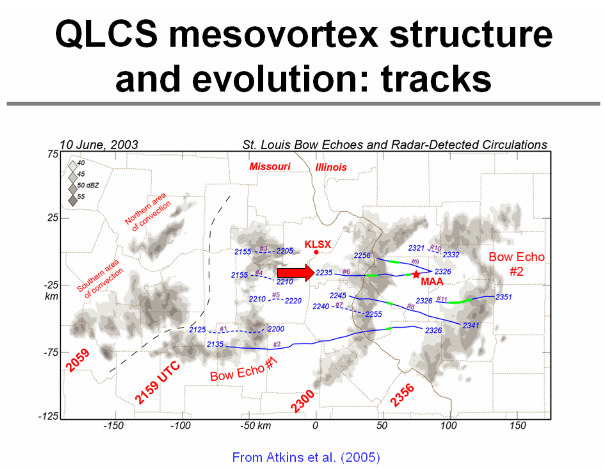
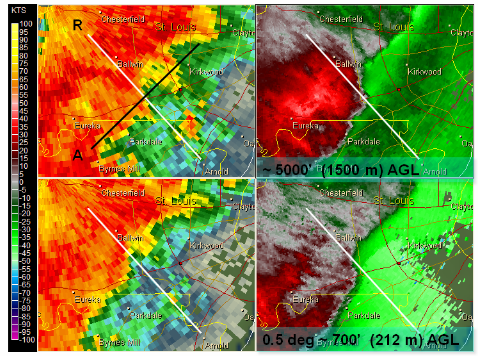


18. A typical severe mesovortex initiation (t=0 min)

Instructor Notes: At 2235 UTC on June 10, 2003, mesovortex #6 was initially tracked. You can see two elevations in this four-panel with SRM on the right, one at 5000' ARL and the other, 700' ARL (lowest elevation scan). Note that the lowest scan shows a gust front that's beginning to become kinked. Notice southwest of the kink, a strong RIJ with outbounds approaching 40 kts. Recall that this SRM display removed about 270 deg at 35 kts already. This mesovortex that's forming doesn't have an obvious maximum and minimum velocity core like you'd expect in a traditional mesocyclone, however there is a local vorticity maximum that the updraft along the gust front can easily amplify. Let's take a look at two cross-sections, an Azimuthal one to see the mesovortex, and then a Radial one to see the QLCS structure.

Student Notes:

A typical severe mesovortex initiation (t=0 min)

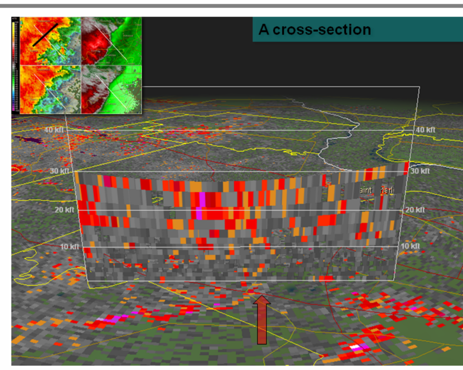


19. Azimuthal Cross-section: mesovortex initiation

Instructor Notes: First, the azimuthal cross-section shows heavy cores overlying a weak echo region. Remember that system motion may have caused an artificial WER. Going to velocity, the cross-section falls from within the protruding gust front then across it into the pre-storm air. The gust front at the kink is nearly vertical for the lowest 10 kft ARL with an abrupt cutoff. This structure is pretty typical and sometimes the mesovortex will be stronger down low. Spectrum width shows a zone of slightly higher values along the gust front interface, and then over the gust front. The high values above may simply be due to turbulence in the convective core.

Student Notes:

Azimuthal Cross-section: mesovortex initiation

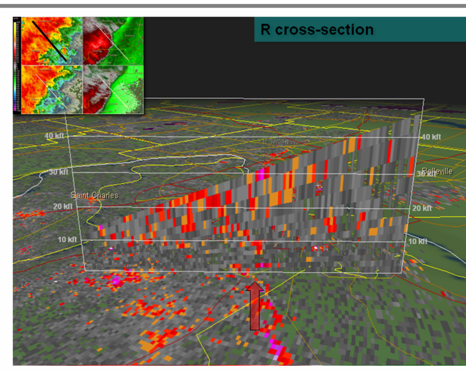


20. Radial Cross-section: mesovortex initiation

Instructor Notes: The Radial reflectivity cross-section shows that what may have been an artificial WER may be partly real since the strong echo overhang extends so far forward. The core is certainly at least led by a wall of high reflectivity gradient that typifies severe QLCSs. The SRM shows an intense nondescending rear inflow jet right up just behind the gust front of 10 kft depth. Note that there is an artificial forward tilt to the gust front due to system motion. Notice that the artificial displacement is not as far as the forward displacement of the intense reflectivity core so we are seeing true intense reflectivity echo overhang. Spectrum width shows again the most turbulence along, and above the gust front with low values in the RIJ core and in the pre-storm inflow. Signs that we will have a severe mesovortex event are already here. They include a nearby association of the intense RIJ with the low-level onset of the mesovortex, and a deep gust front and deep convection coincident with each other.

Student Notes:

Radial Cross-section: mesovortex initiation



21. QLCS mesovortex structure and evolution: Time height

Instructor Notes: Adding a time-height profile, what you've just seen is marked by the arrow. In the upper-left panel, rotational velocity shows values peaking at 11 m/s (21 kts). But notice that the highest values are just above the lowest scan. This is a frequent behavior where scans above the ground up to 1-2 km have somewhat stronger values than at the lowest scan. So if you're radar is nearby, going up a scan or two may help show a more stout mesovortex. However, the mesovortex is still shallow and not exceeding 1.5 km AGL as documented by Atkins et al. 2005. The following 10 minutes show rapid deepening and strengthening of the vortex as you can see in the time trends of rotational velocity in the upper right. Notice that the azimuthal shear values in the lower right are right in line with any significant supercell mesocyclone (>10X10E-3 per second). Different than a typical mesocyclone, notice the diameter of this mesovortex is quite small, only 2 km (1.2 nm). The mesovortex occasionally peaked above 5 km as it matured and produced a sequence of tornadoes. Intensification occurred prior to or at least during tornadogenesis, a typical behavior. Also notice the long lifespan of the mesovortex. It would be nice to take warn the initial deepening and intensification of this mesovortex before tornado time but you can also be more comfortable with followup warnings based on its persistence. Let's take a look at this mesovortex at a mature stage just prior to the first tornado.

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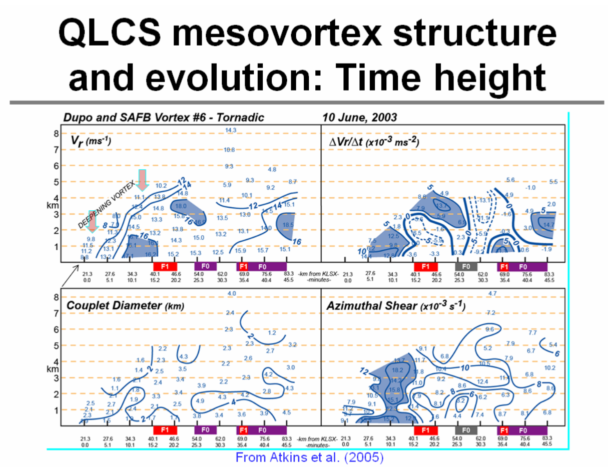
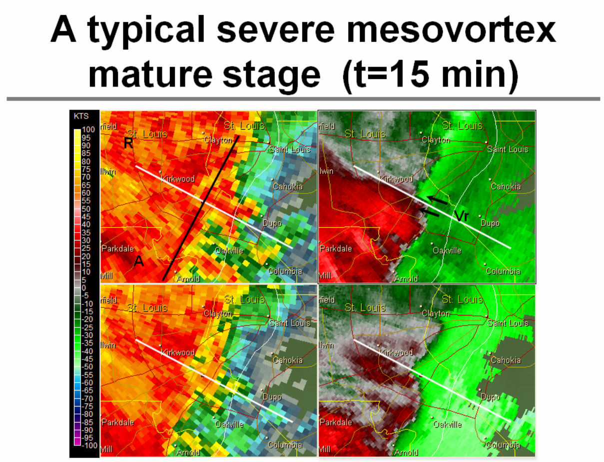


22. A typical severe mesovortex mature stage (t=15 min)

Instructor Notes: Shifting 10 minutes later, the mesovortex looks much stronger at the 5000' ARL level (top) with now what appears to be at least an isolated velocity minimum (inbound) on the top and even a hint of a core of maximum outbounds south of the center. The lowest scan also shows at least a maximum velocity core and even a hint that an azimuthal gate-to-gate velocity couplet is forming. These values were used to calculate the Vr in the time height trace. In the reflectivity, there's a little confusion in the picture. It appears that strong reflectivity has swallowed the mesovortex. However, there were some convective cells merging with the main line. So look left of the radial cross-section line and you see an S-shaped reflectivity gradient where the inflection point is right on the mesovortex. Also note southwest of the mesovortex you still see evidence of the RIJ in both the SRM and the rear inflow notch. All these are components of a severe mesovortex. Let's look at the cross-sections starting with the azimuthal one (A).

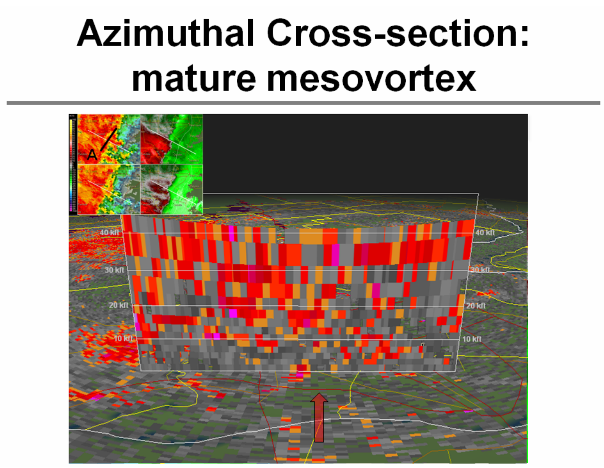
Student Notes:



23. Azimuthal Cross-section: mature mesovortex

Instructor Notes: Again the reflectivity pattern looks a little muddy because of the merging cells. The SRM now shows the mesovortex extending to 15 kft (~5 km) ARL. The strongest rotational velocity still is in the lowest part of the mesovortex. This time the spectrum width highlights a bullseye of high values at the low-level mesovortex center.

Student Notes:

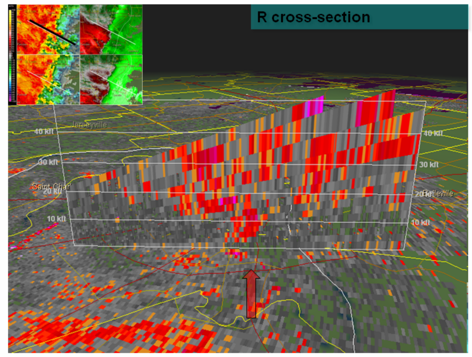


24. Radial Cross-section: mesovortex initiation

Instructor Notes: At 2245 UTC or initiation + 15 minutes, that same overhang is still visible, that is with the main convective line, and even the merging cell. Base velocity shows the RIJ right behind and leading into the south side of the mesovortex. The gust front has deepened behind the mesovortex, almost 15 kft ARL! All the winds in yellow are meeting severe thresholds or more. Notice in the SRM the big convergence down low, the strong rearward flow above the deep gust front and then the anvil layer outflow to the right. This is a pattern typical of a high-end severe QLCS. The SW shows again the vortex bullseye down low and the high values along and above the gust front interface. But the inflow and initial updraft ahead of the gust front are relatively smooth, as is the RIJ core.

Student Notes:

Radial Cross-section: mesovortex initiation



25. Interim summary: severe mesovortex evolution

Instructor Notes: To summarize, we had a nondescending vortex though it may appear weaker down in the lowest layer. The strong RIJ on the right side and behind the mesovortex is a serious precursor of a severe mesovortex. The mesovortex was not a classic Rankine combined archetype. We could see the deepening vortex as it matured and a more classic look as it garnered a min and max velocity. The convection was upright and even featured a WER. Front and rear inflow notches formed. SW was also useful to snag the vortex location as long as you know where to look since there's lots of other high SW centers.

Student Notes:

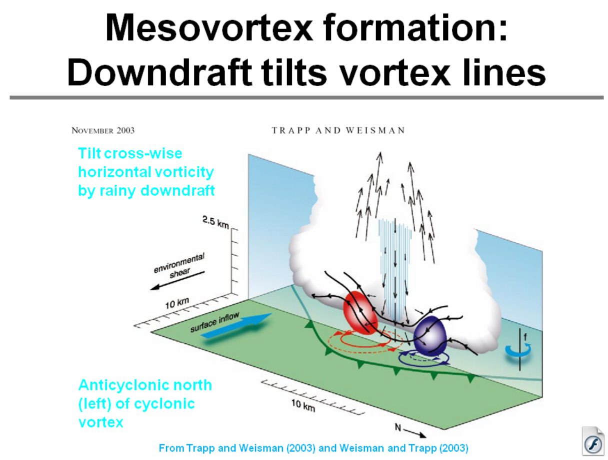
Interim summary: severe mesovortex evolution

- Nondescending vortex
  - However the vortex may appear weak below 2000' AGL
- Strong RIJ on the right (south) a precursor
- Did not initiate as an ideal Rankine combined vortex
  - Measured Vr from where max and min velocity plateaus
- Upright convection, even a WER
- Front and rear inflow notch
- SW useful when combined with velocity

26. Mesovortex formation: Downdraft tilts vortex lines

Instructor Notes: Researchers have been trying to establish how QLCS mesovortices form and as expected there's more than one answer. This result that popped up in a separate window, featured one of the first theories and it's one that we still consider. That is a localized strong downdraft formed behind the gust front and depressed the vortex lines along the cold pool boundary eventually leading to a couplet. This evolution results in a vortex couplet with the anticyclonic member north or to the left if your pointed in the direction that the QLCS is moving. Not many warning forecasters have seen this kind of vortex couplet but there's evidence in BAMEX that they exist, perhaps mainly in the early stages of a QLCS before the RIJ really has a chance to mature. The anticyclonic member dies off quickly as it fights against Earth's vorticity.

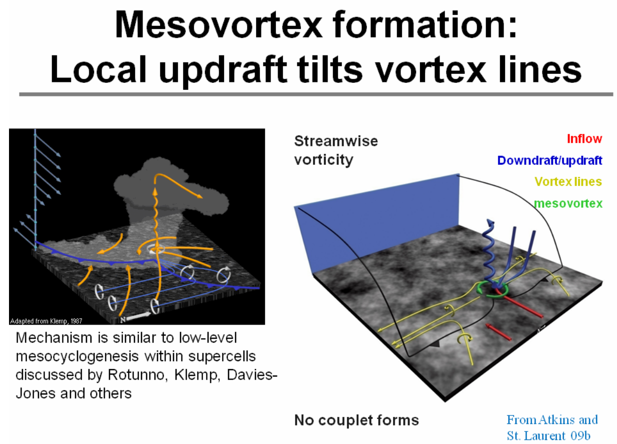
Student Notes:



27. Mesovortex formation: Local updraft tilts vortex lines

Instructor Notes: More recently, Atkins and Laurent developed more than one theory for mesovortex formation because they saw different evolutions within the QLCS. This one requires a locally intense updraft along the gust front to tilt and stretch streamwise vorticity running down the boundary. The resulting vortex would be of a single sign and not a couplet. A similar theory for mesocyclone formation looks quite similar developed by Rotunno, Klemp, Davies-Jones and others. Instead of a QLCS gust front it's the forward flank gust front that helps. However mesocyclones happily form just tilting environmental streamwise vorticity without needing a forward flank gust front.

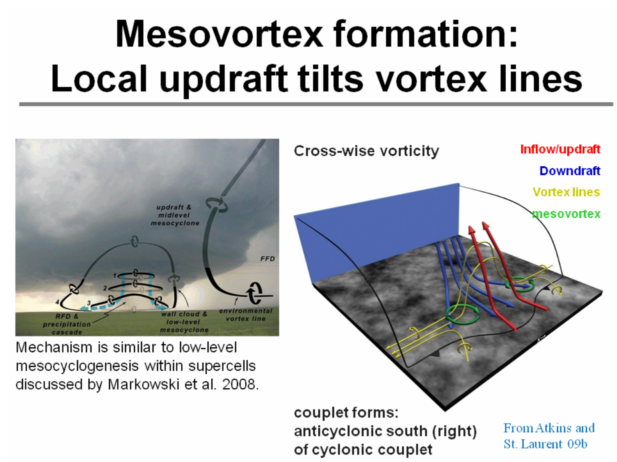
Student Notes:



28. Mesovortex formation: Local updraft tilts vortex lines

Instructor Notes: This other evolution in mesovortexgensis was found by Atkins and Laurent where instead of an isolated updraft pulling up streamwise vorticity, a local outward bulge in the gust front forms, possibly from the RIJ axis or a local downdraft. A horseshoe vortex arch forms with the cyclonic member on the north side (or left pointing ahead of the QLCS). This couplet is in the opposite sense to what Trapp and Weisman theorized and it's something we see more often, especially during the mature RIJ stage of the QLCS. Notice that this evolution is quite similar to what Markowski et al. 2008 theorized with the formation of a low-level mesocyclone in a supercell. In the supercell case, air from the downdraft descends, creates cross-wise vortex lines around its exterior, in the form of a horseshoe. Some of those vortex lines get entrained into the updraft. Notice that they distinguish those vortex lines from the environmental vortex lines that help create the midlevel mesocyclone.

Student Notes:



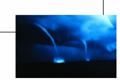
29. Mesovortex formation: Implications

Instructor Notes: So we described downdrafts directly tilting cold pool vortex lines to create a couplet with cyclonic (anticyclonic) member to the right (left). Then we talked about updraft tilting streamwise vortex lines to generate a singular cyclonic vortex, and we discussed the formation of vortex arches to create a couplet with the cyclonic (anticyclonic) member to the left (right). We didn't talk about horizontal shearing instability. Basically here the gust front vertical vorticity gets so large that it breaks down into regularly spaced vortices of the same sign, namely cyclonic. So the difference between this and the local updraft tilting streamwise vorticity is that first, we don't know how that vertical vorticity got there to be rolled up, and the local updraft tilting doesn't produce regularly spaced vortices at the same time. I think you've seen pictures of multiple waterspouts occurring simultaneously. That's a manifestation of shear instability, and the same thing could happen on a QLCS gust front.

Student Notes:

Mesovortex formation: Implications

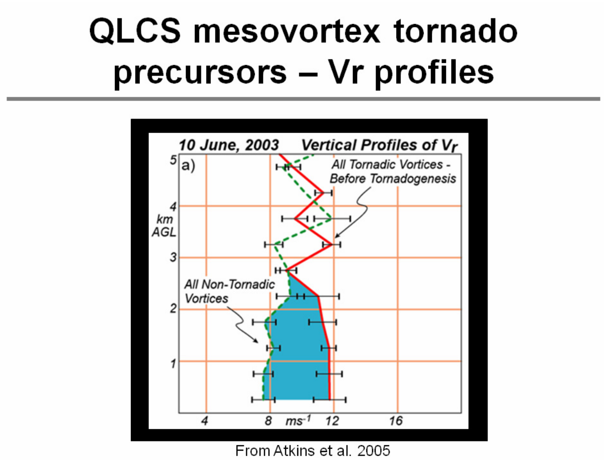
Formation process	Implication (assuming westerly environmental shear)
Downdraft tilting cold pool vortex lines	Couplets: Anticyclonic mesovortex forms north of cyclonic mesovortex
Local updraft tilts streamwise vortex lines	No couplets: Multiple mesovortices irregularly spaced
Local updraft tilts crosswise vortex lines	Couplets: Anticyclonic mesovortex forms south of cyclonic mesovortex
Horizontal shearing instability	No couplets: Multiple mesovortices spaced at regular intervals.



30. QLCS mesovortex tornado precursors – Vr profiles

Instructor Notes: There hasn't been a lot of work done in the field of discriminating tornadic vs. nontornadic QLCS mesovortices but what there is appears to be fairly applicable. The 10 June 2003 case had a clear discrimination between tornadic and nontornadic mesovortices. In this figure the mean rotational velocity of the tornadic mesovortices as a function of height shows how much stronger they were than for the nontornadic mesovortices, especially from 2 km AGL down toward the surface. So at least for this case, the mean Vr for tornadic mesovortices was around 24 kts (12 m/s). There needs to be more work to show how well this discrimination goes for a large sample of cases. However, the take home message is that the tornadic mesovortices are much stronger at low-levels.

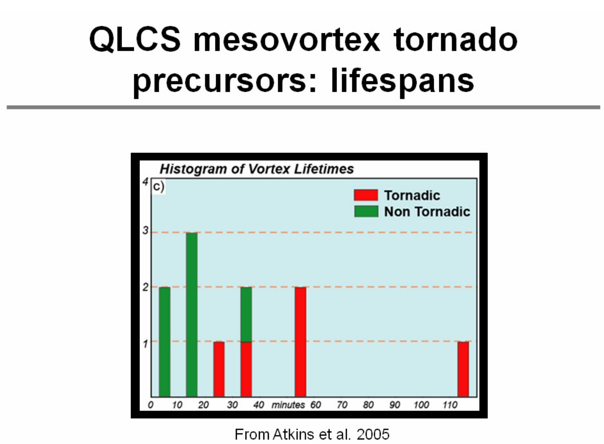
Student Notes:



31. QLCS mesovortex tornado precursors: lifespans

Instructor Notes: In terms of longevity, the 10 June 2003 tornadic mesovortices lasted longer than those that were nontornadic. Again, the sample size is somewhat limited but there is evidence that this trend holds true for a larger set of cases too. As a warning forecaster, you don't have time to see if a particular mesovortex is going to last a long time, otherwise you'd have to sacrifice a lot of people before issuing a warning. But you can certainly increase your confidence in your warnings as the mesovortex continues to persist, and especially if its strong and long-lived.

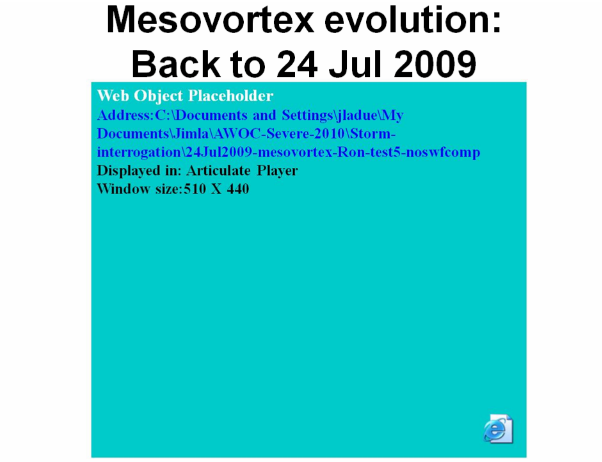
Student Notes:



32. Mesovortex evolution: Back to 24 Jul 2009

Instructor Notes: Going back to the 24 July 2009 case, Ron will be walking you through the evolution of a particular mesovortex as he would do in a warning decision making mode. This video lasts about 3 minutes.

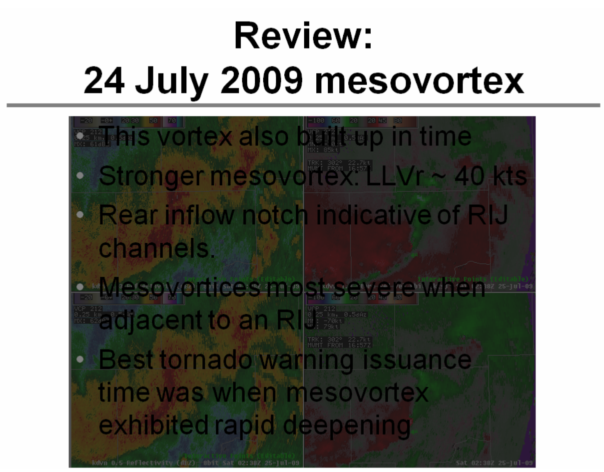
Student Notes:



33. Review: 24 July 2009 mesovortex

Instructor Notes: The main message from Ron's discussion is: This vortex also built up in time Stronger mesovortex: LLVr ~ 40 kts Rear inflow notch indicative of RIJ channels. Mesovortices most severe when adjacent to an RIJ Best tornado warning issuance time was when mesovortex exhibited rapid deepening

Student Notes:

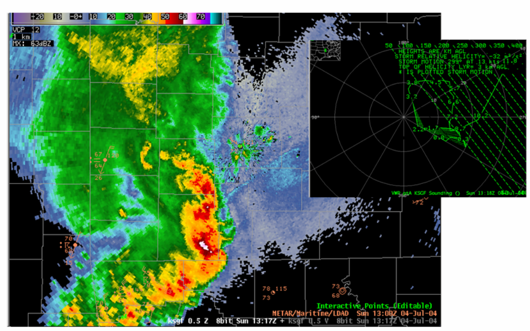


34. Along-line variations: intersecting boundaries

Instructor Notes: As a final major topic, this lesson wouldn't be complete without discussing the impacts of heterogeneity (e.g., boundaries, mergers) on QLCS severity, especially on mesovortex behavior. There's quite a bit of work done on how boundaries and merging instability lines impact QLCSs but rather than recite all the work, let's apply it to this case, 04 July 2004, that we've been going through in this lesson. We already eluded to the presence of a pre-line boundary in this case extending to the southwest creating an intersection. Let's start at 1153 UTC and we'll see how the boundary has impacted the pre-storm environment. There's not much to go on except a couple METAR stations, Joplin and Springfield, and the Springfield WSR-88D VWP. The post boundary air is important to sample because it'll determine how well the bow can survive on that side. But also equally important is how the boundary-bow intersection plays a role in enhancing mesovortexgenesis. For this page, we'll concentrate on the post-boundary air. I included the SGF raob hodograph at 12 UTC to show that there's a fairly complex shear profile from 0 – 3 km AGL and a general west-northwest bulk wind difference of 30 kts from 0 – 6km AGL. At 1153 UTC, the boundary has just passed Joplin and we can see the temperature hasn't dropped yet. The apex of the bow is directly in line with the boundary. At 1214 UTC, the KSGF wind profile shows a complex vertical wind profile but the VWP is not picking up the lowest level winds. There's perhaps a tendency for a northeasterly 0-3 km shear vector averaging the lowest few hundred meters within the surface and a similar layer around 3 km AGL. At 1240 UTC, the boundary passes over the radar and the surface winds go from southwest to northwest. The vertical shear is still complex. At 1300 UTC, There is a marked increase in southeasterly shear within the boundary layer with northwesterly surface winds and almost southerly 3 km winds. Above 3 km the wind shear reverses to northerly again. This feature persists through the end of the loop. The 0-3km shear is much stronger but in this case may not actually be conducive to enhancing the strength of the line since the predominant component of the shear is line-parallel, even front to rear. Notice that the northern end of the line never extends far beyond the boundary intersection. As far as instability is concerned, the SGF METARs eventually drop from 75 deg F just north of the boundary to 73 deg F an hour later. However the dewpoint remained higher than the pre-boundary air. It's not clear that the instability decreased rapidly north of the boundary but the shear could've had a negative impact on the QLCS survival. Had the shear been oriented from the WSW behind the boundary, the QLCS may have threatened Springfield with potential mesovortices. But most likely for the shear to be oriented from the WSW, the post boundary wind direction would've needed an easterly component, an attribute most commonly associated with a stalling, or even lifting outflow boundary.

Student Notes:

Along-line variations: intersecting boundaries

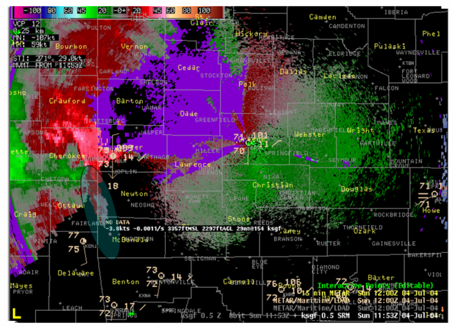


35. Along-line variations: Merging ascent zones

Instructor Notes: If the horizontal shear along and north of the boundary is not conducive for maintaining the QLCS, then perhaps another one or two other sources could help to increase the threat of a severe mesovortex. One could be the enhanced convergence at the boundary intersection, and another could be the intersection of other convective cells, or the forcing mechanism producing them. In this case, there's a double intersection between an instability line forcing an axis of broken cells and the boundary at the same time. The locally stronger convergence here could easily have locally amplified any vertical vorticity lying along either boundary into a well defined vortex. Lese, 2006 noticed that the mesovortex that coincided with this double intersection resulted in a tornado while an adjacent mesovortex to the south did not. In the next slide, Ron will describe his thought process in warning forecaster mode.

Student Notes:

Along-line variations: Merging ascent zones



36. Along-line variations and mesovortices: 04 Jul 2004

Instructor Notes: Ron will be showing you the evolution of this particular mesovortex and how it relates to the surrounding intersections. Take note of his interrogation of its evolution with time and height too.

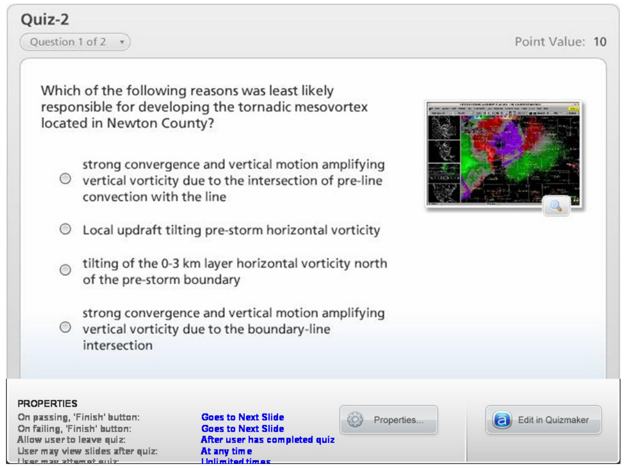
Student Notes:

Along-line variations and mesovortices: 04 Jul 2004

37. Quiz-2

Instructor Notes:

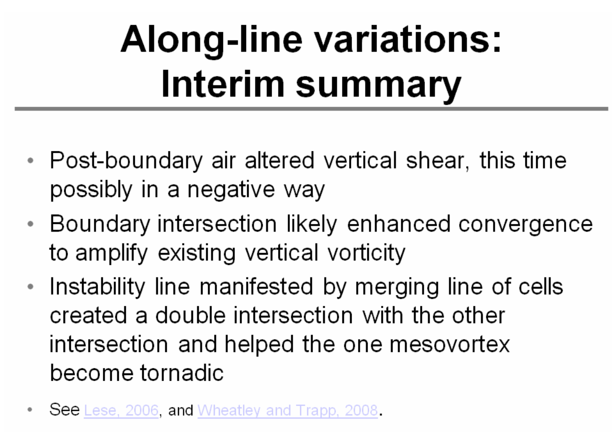
Student Notes:



38. Along-line variations: Interim summary

Instructor Notes: Post-boundary air altered vertical shear, this time possibly in a negative way Boundary intersection likely enhanced convergence to amplify existing vertical vorticity Instability line manifested by merging line of cells created a double intersection with the other intersection and helped the one mesovortex become tornadic

Student Notes:



39. Summary

Instructor Notes: What stages in a QLCS lifecycle are most likely to produce the most severe wind (tornado) potential? During and after formation of the RIJ What kinds of 3-D structure are most related to the most intense severe wind (tornadic) events? Look for deep and steep gust front with a deep convergence zone and attached to a solid wall of deep convection. What is a common evolution of convection preceding the formation of bows? Merging small multicells and associated cold pools What is the motion of typical bows? Typically with the mean convective layer wind and faster

Student Notes:

Summary

- What stages in a QLCS lifecycle are most likely to produce the most severe wind (tornado) potential?
  - During and after formation of the RIJ
- What kinds of 3-D structure are most related to the most intense severe wind (tornadic) events?
  - Look for deep and steep gust front with a deep convergence zone and attached to a solid wall of deep convection.
- What is a common evolution of convection preceding the formation of bows?
  - Merging small multicells and associated cold pools
- What is the motion of typical bows?
  - Typically with the mean convective layer wind and faster

40. Summary - contd

Instructor Notes: How do mesovortices form? downdraft tilting vortex lines behind gust front, local updraft tilting streamwise vorticity on gust front, updraft tilting cross-wise vorticity over protruding gust front When are mesovortices most likely to become severe (wind and tornado)? After the RIJ forms and moves adjacent to a mesovortex How do I discriminate tornadic from nontornadic mesovortices? Stronger rotational velocity, depth, lifespan, environment When is the best time to issue a warning on a mesovortex? As the mesovortex begins to deepen

Student Notes:

Summary - contd

- How do mesovortices form?
  - downdraft tilting vortex lines behind gust front, local updraft tilting streamwise vorticity on gust front, updraft tilting cross-wise vorticity over protruding gust front
- When are mesovortices most likely to become severe (wind and tornado)?
  - After the RIJ forms and moves adjacent to a mesovortex
- How do I discriminate tornadic from nontornadic mesovortices?
  - Stronger rotational velocity, depth, lifespan, environment
- When is the best time to issue a warning on a mesovortex?
  - As the mesovortex begins to deepen

41. Summary - contd

Instructor Notes: How can a pre-storm boundary enhance mesovortices? Increasing pre-storm vertical shear, enhancing convergence at the intersection point Does a pre-storm outflow boundary or warm front always enhance mesovortices? No, we need to worry about stability and shear changes as always

Student Notes:

42. Credits

Instructor Notes:

Student Notes:

43. Contact Information

Instructor Notes: Get in touch with us should you have a question or would like to chat about severe weather.

Student Notes:

Contact Information

- awocsevere_list@wdtb.noaa.gov
  - Questions on any AWOC Severe lessons
- NWS-chat
  - wdtbchat chat room
- James G. LaDue
  - James.G.LaDue@noaa.gov
  - 405-325-3004