# 1. Storm Interrogation

**Instructor Notes:** slide 1: AWOC Severe Track. IC3-II-B Storm Interrogation - Updraft Strength from Low-level Convergence. This lesson covers detecting and estimating the effects that low-level convergence has on updraft strength. There are 17 pages in this lesson and it should take about 20 minutes to finish.

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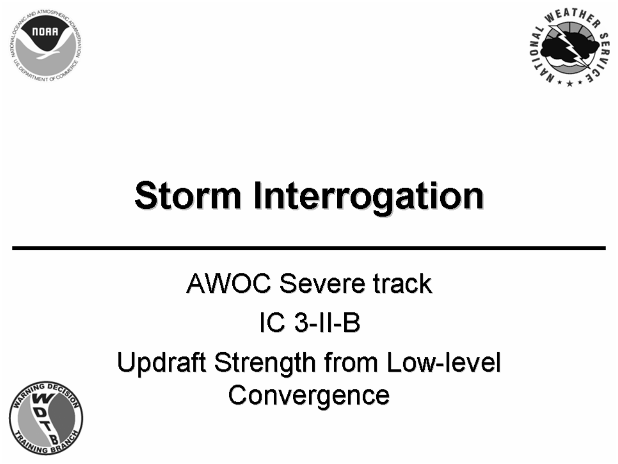

### Storm Interrogation

AWOC Severe track
IC 3-II-B
Updraft Strength from Low-level Convergence

# 2. Updraft strength– Low-level convergence

**Instructor Notes:** At the end of this presentation, you should understand the contribution of low-level convergence to CAPE on updraft intensity   You may not be able to provide specific values on how strong an updraft is likely to be, but you will have gained an appreciation in how updraft strength can be significantly enhanced beyond what the theoretical CAPE can provide in certain situations.

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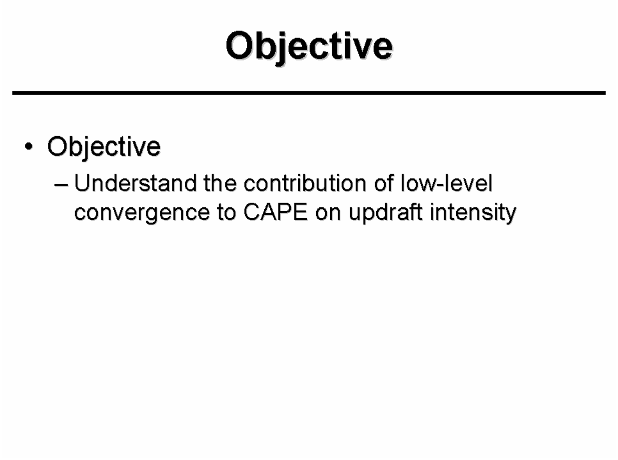


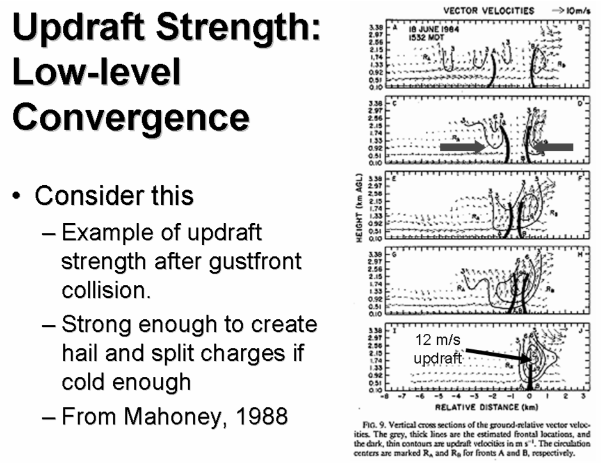
### Objective

- Objective
  - Understand the contribution of low-level convergence to CAPE on updraft intensity

## 3. Updraft strength – Low-level convergence

**Instructor Notes:** Consider this example of dual-Doppler derived velocities of a colliding gustfront visualized in this cross-section taken from Mahoney (1988). A gustfront one km deep colliding at a combined speed of 13 m/s can produce an updraft of similar strength at 3 km above ground. Cloud physics and storm electrification research (See papers by Zipser and Marwitz) suggest storm electrification begins wen updrafts exceed 5m/s. Without any CAPE, we could've initiated lightning had the atmosphere been cold enough to produce graupel. This is not the case since this updraft forcing is too shallow to extend into cold enough air, however it does show that if this lowlevel forcing were to occur under a developing towering cumulus, the extra boost would give this cumulus a much greater initial updraft strength than a neighboring cumulus away from this forcing.

**Student Notes:**



**Updraft Strength: Low-level Convergence**

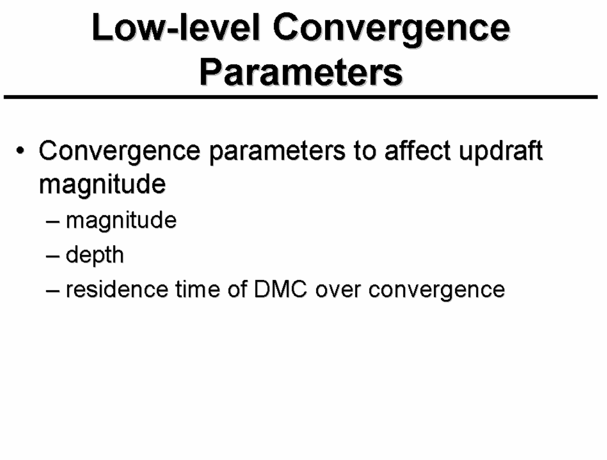
- Consider this
  - Example of updraft strength after gustfront collision.
  - Strong enough to create hail and split charges if cold enough
  - From Mahoney, 1988

FIG. 9. Vertical cross sections of the ground-relative vector velocities. The grey, thick lines are the estimated frontal locations, and the dark, thin contours are updraft velocities in m $s^{-1}$. The circulation centers are marked $R_A$ and $R_B$ for fronts A and B, respectively.

## 4. Updraft strength – Low-level convergence

**Instructor Notes:** Several considerations need to be accounted for in determining how much of an initial boost to buoyancy convergence may give to a storm. The magnitude of convergence is one for obvious reasons, Stronger updraft results from stronger convergence. However, I could have a situation where an adjacent gustfront may be weaker in convergence magnitude but it's forcing deeper convergence. The second consideration, convergence depth, is equally important to magnitude when the final updraft speed is concerned. Finally, when an airparcel responds to the forcing that has created the convergence, it starts to accelerate as long as that forcing is there. If the forcing is cutoff, the final vertical velocity of that parcel will have failed to reach its full potential.   One thing to remember, convergence is not a forcing mechanism. Something forces the convergence, and likewise the vertical velocity. This has implications for my scenarios coming in the following pages.

**Student Notes:**



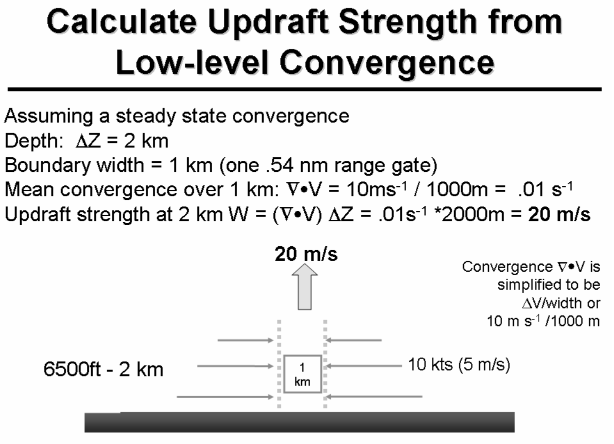
Low-level Convergence Parameters

- Convergence parameters to affect updraft magnitude
  - magnitude
  - depth
  - residence time of DMC over convergence

# 5. Updraft strength – Low-level convergence depth

**Instructor Notes:** . I will show a few examples of changing the convergence depth and magnitude across a boundary. The vertical velocity that arises out of the convergence, I estimate using the continuity equation greatly simplified so that you see the results more clearly. I mentioned before that convergence is not a forcing, it is just a diagnostic. What forced the convergence and its vertical motion field may be from a thermal gradient, or density gradient like you see across a gust front. In this scenario, I have a 2km deep boundary where the average flow toward the center interface is 10kts. That means my velocity difference is 20 kts (10m/s). The boundary is roughly 2 km wide. First, I estimate the mean convergence across the width of that convergence by dividing the velocity difference by the width of the boundary (all in meters and seconds). Then I multiply my convergence by the depth of the mean convergence (2000 m). My answer comes out to 10 m/s at 2 km altitude. The boundary may be a bit deep but it's also a bit wider than a real boundary. Most fine lines are 2km wide or less.

**Student Notes:**



Calculate Updraft Strength from Low-level Convergence

Assuming a steady state convergence
Depth: $\Delta Z = 2$ km
Boundary width = 1 km (one .54 nm range gate)
Mean convergence over 1 km: $\nabla \bullet V = 10 ms^{-1} / 1000m = .01 s^{-1}$
Updraft strength at 2 km $W = (\nabla \bullet V)\, \Delta Z = .01 s^{-1} * 2000m =$ **20 m/s**

Convergence $\nabla \bullet V$ is simplified to be $\Delta V$/width or 10 m $s^{-1}$ /1000 m

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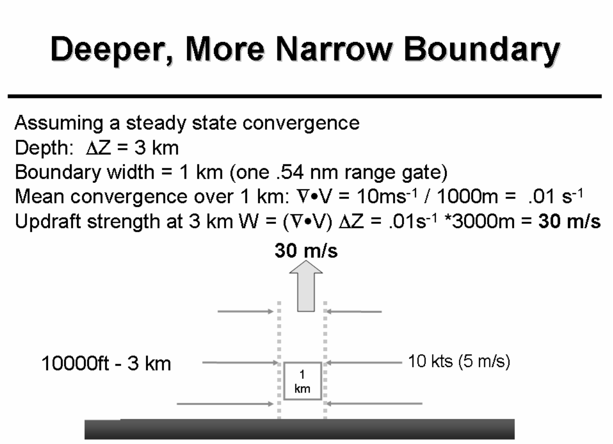
# 6. Updraft strength – Low-level convergence depth

**Instructor Notes:** If I change my boundary depth to something deeper, maybe a deep convergence zone along a squall line gust front, my final vertical velocity at the top of my convergence (3 km) is 15 m/s, certainly strong enough to generate hail if the air temperature was cold enough.

**Student Notes:**



**Deeper, More Narrow Boundary**

Assuming a steady state convergence
Depth: $\Delta Z = 3$ km
Boundary width = 1 km (one .54 nm range gate)
Mean convergence over 1 km: $\nabla \bullet V = 10 ms^{-1} / 1000m = .01 s^{-1}$
Updraft strength at 3 km $W = (\nabla \bullet V)\ \Delta Z = .01s^{-1} * 3000m =$ **30 m/s**

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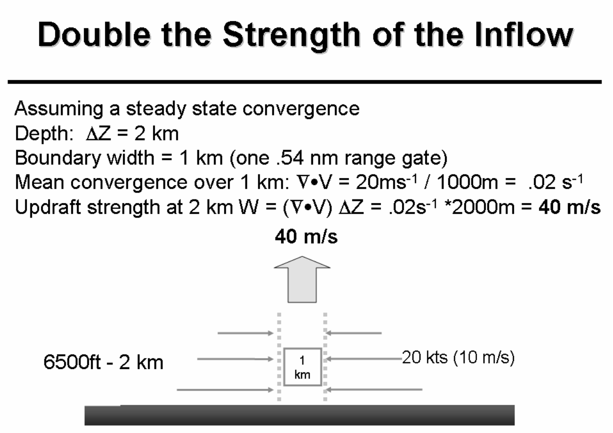
# 7. Updraft strength – Low-level convergence strength

**Instructor Notes:** Going back to my 2 km deep boundary, now I double my inflow. Now I get a 20 m/s updraft at 2 km, that's double my previous 2 km deep boundary after doubling the inflow. This may be a realistic squall line gust front which is moving at 40 kts. Remember, these are for illustrative purposes only. There are a lot of factors that may work against realizing these updraft numbers including the residence time of any parcel in the zone of convergence, entrainment, etc.

**Student Notes:**



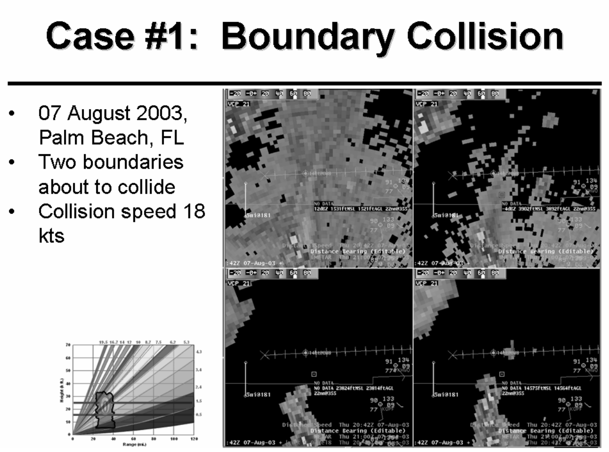
**Double the Strength of the Inflow**

Assuming a steady state convergence
Depth: $\Delta Z = 2$ km
Boundary width = 1 km (one .54 nm range gate)
Mean convergence over 1 km: $\nabla \bullet V = 20 ms^{-1} / 1000m = .02 s^{-1}$
Updraft strength at 2 km $W = (\nabla \bullet V)\ \Delta Z = .02s^{-1} * 2000m =$ **40 m/s**

## 8. Case: Boundary collision

**Instructor Notes:** Here's an example from Florida of a boundary collision from 07 August 2003 near Palm Beach, FL. I tracked the motion of these two boundaries with the distance speed tool in AWIPS to get a combined collision speed of 18 kts. Looking at my 4-panel, I'm having trouble observing the boundaries above the 1.5° elevation slice, so I may have a good idea on the depth of the gust fronts. But what is the convergence?

**Student Notes:**



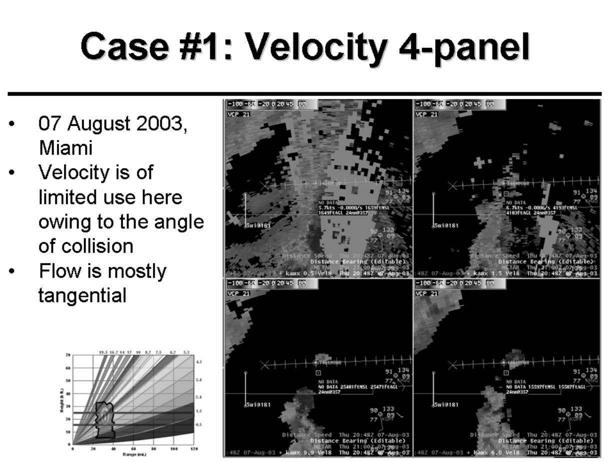
Case #1: Boundary Collision

- 07 August 2003, Palm Beach, FL
- Two boundaries about to collide
- Collision speed 18 kts

## 9. Case: Boundary collision

**Instructor Notes:** Looking at the velocity, I have a problem. The velocities are weak, probably because the winds in either cold pool are mostly tangential. I cannot use the velocity data to come up with an estimate on convergence.

**Student Notes:**



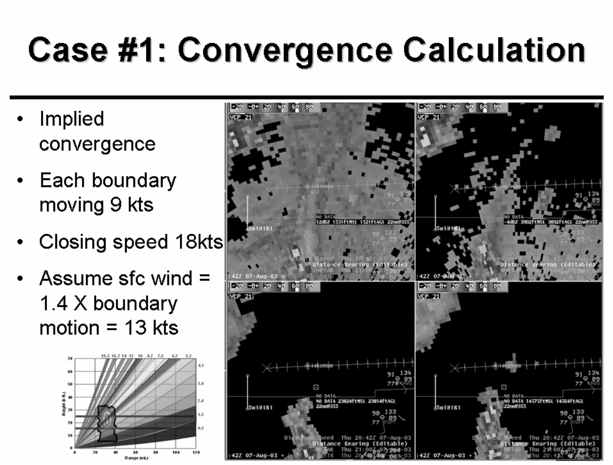
Case #1: Velocity 4-panel

- 07 August 2003, Miami
- Velocity is of limited use here owing to the angle of collision
- Flow is mostly tangential

## 10. Case: Boundary collision

**Instructor Notes:** We will have to imply convergence based on an estimate of the winds behind each boundary. The closing speed of each boundary is roughly 18kts. Mahoney (1988) found that surface 10m winds behind a gust front was roughly 1.4 times that of the boundary motion after sampling a large number of boundaries. Apply that here to each boundary motion of 9 kts and we have winds roughly 13 kts in each boundary. After collision, the combined differential velocity may be 26 kts. Note that the relation between boundary speed and maximum wind speed behind the boundary assumes a relatively calm pre-boundary environment. This relation works for this case. This relation needs to be revised for strong low-level wind events,.

**Student Notes:**



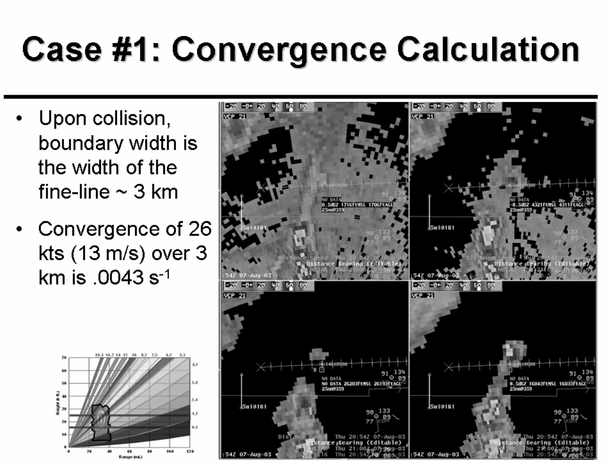
Case #1: Convergence Calculation

- Implied convergence
- Each boundary moving 9 kts
- Closing speed 18kts
- Assume sfc wind = 1.4 X boundary motion = 13 kts

## 11. Case: Boundary collision

**Instructor Notes:** Radar observed the fineline after collision to be around 3 km wide. Dividing 13 m/s (26 kts) by the width of the fineline in meters gives me a convergence of 0.004 /s. This is going to be the maximum convergence near ground level. That convergence should be weaker going up in altitude. But let's keep this convergence for the lowest one km above the ground.

**Student Notes:**



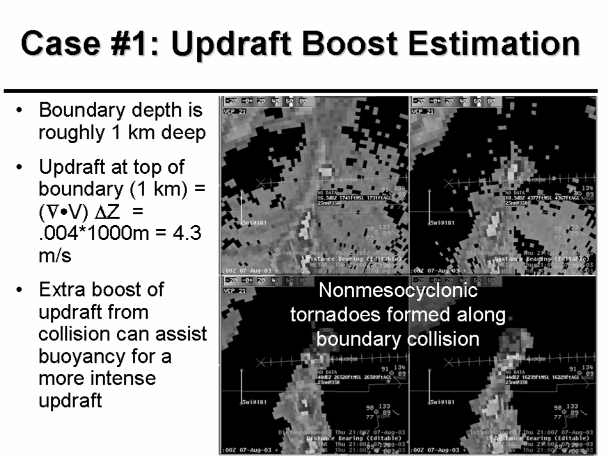
Case #1: Convergence Calculation

- Upon collision, boundary width is the width of the fine-line ~ 3 km
- Convergence of 26 kts (13 m/s) over 3 km is .0043 $s^{-1}$

## 12. Case: Boundary collision

**Instructor Notes:** By the simplified continuity principle, multiple the convergence by its depth of one km and we get an updraft speed of 4.3 m/s at the top of the boundary. A developing towering cumulus is likely and initiation will be strongly forced compared to a other developing convection from most other initiation mechanisms this day. As can be seen, convective cells rapidly developed along and after the collision.

**Student Notes:**



Case #1: Updraft Boost Estimation

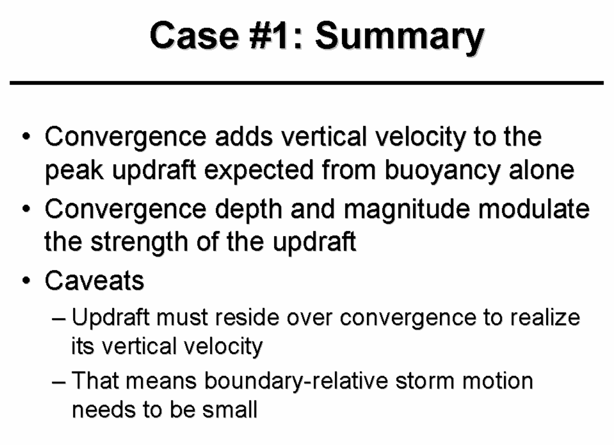
- Boundary depth is roughly 1 km deep
- Updraft at top of boundary (1 km) = $(\nabla \bullet V)\ \Delta Z$ = .004*1000m = 4.3 m/s
- Extra boost of updraft from collision can assist buoyancy for a more intense updraft

Nonmesocyclonic tornadoes formed along boundary collision

## 13. Summary: Case 1 – Pulse storm updraft

**Instructor Notes:** To summarize this event, the boundary collision may have added up to 8 kts of vertical velocity to the base of the convective updrafts. In addition, large plumes of moisture have been advected upward to produce a much stronger base for buoyancy to continue the initiation process. The result was a more intense set of thunderstorm updrafts than the initial storms that created the original cold pool boundaries in the first place. There are some caveats to everything. First, the convective layer steering flow must be such as to minimize boundary-relative storm motion in order to generate the strongest, deepest updraft possible. Deep layer shear should be optimally balanced with the motion of the gust front to generate a deep overturning convective current. In this event, shear is not a consideration in the environment, storm motion was small, and the updraft generated by the boundary collision was likely upright and deep.

**Student Notes:**



### Case #1: Summary

- Convergence adds vertical velocity to the peak updraft expected from buoyancy alone
- Convergence depth and magnitude modulate the strength of the updraft
- Caveats
  - Updraft must reside over convergence to realize its vertical velocity
  - That means boundary-relative storm motion needs to be small

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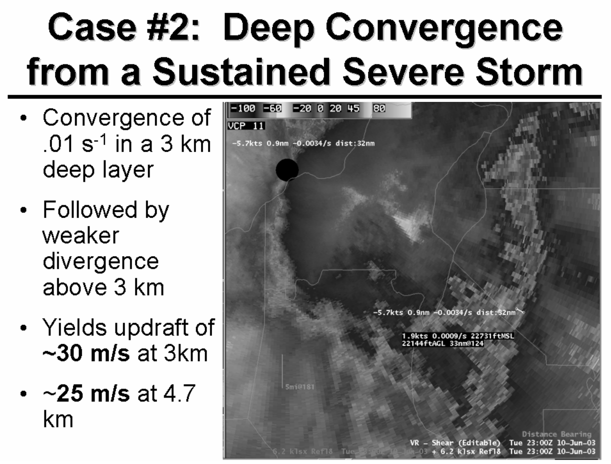
## 14. Case 2: Deep convergence from sustained severe storm

**Instructor Notes:** Here is a case of a severe quasi-linear multicell event with a deep convergence boundary along the gust front. The gust front motion was nearly 50 kts resulting in some very strong convergence. Since velocity is likely mostly radial here, I use the VR-shear tool to estimate convergence across the width of the convergence zone, roughly 1.5 km. The actual zone was probably even narrower than that. This convergence was maintained through the lowest 3 km (10kft). This may be an overestimate but multiplying this convergence through the lowest 3 km resulted in an updraft of nearly 30 m/s at 3 km. Whether or not this is actually the case, the updraft generated here is nearly an order of magnitude higher than the Florida boundary collision case. Imagine this kind of boundary even in a situation where the linear system runs low on CAPE. One could easily imagine this system maintaining itself on its low-level convergence for awhile longer than expected.

**Student Notes:**



Case #2: Deep Convergence from a Sustained Severe Storm

- Convergence of .01 $s^{-1}$ in a 3 km deep layer
- Followed by weaker divergence above 3 km
- Yields updraft of **~30 m/s** at 3km
- ~**25 m/s** at 4.7 km

## 15. Choices

**Instructor Notes:**

**Student Notes:**

Learning Game Placeholder

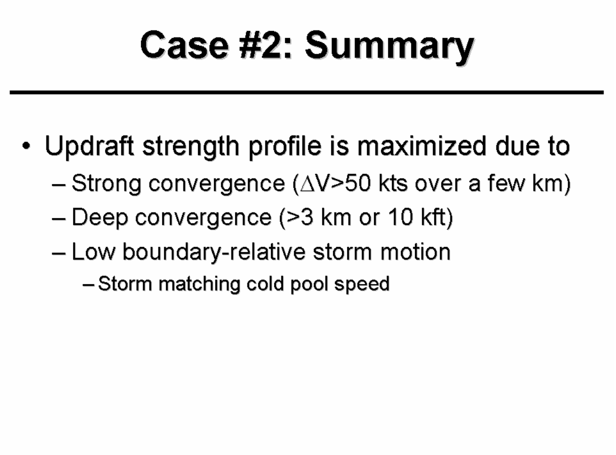
Learning Game: Choices

Title: Test Your Knowledge

## 16. Summary: Case 2 - Strong shear severe storm

**Instructor Notes:** Summarizing, this boundary moving at 50 kts resulted in some incredible convergence, especially considering that the ground-relative low-level inflow was out of the southeast. This convergence was also deep (3 km) and the matching vertical velocity was calculated at 30 m/s at 3 km. The convective layer storm motion allowed the deep updraft to maintain its footing close to the vertical velocity generated by the convergence zone and the result was a deep overturning updraft capable of generating all the features associated with a high end severe squall line including tornadoes, severe low-level winds and excessive rainfall rates. Very severe hail was not something found in this event for many reasons. One of them may be that squall line updrafts tend to flatten out at lower altitudes than for more isolated modes of convection in similar environments.

**Student Notes:**



## Case #2: Summary

- Updraft strength profile is maximized due to
  - Strong convergence (ΔV>50 kts over a few km)
  - Deep convergence (>3 km or 10 kft)
  - Low boundary-relative storm motion
    - Storm matching cold pool speed

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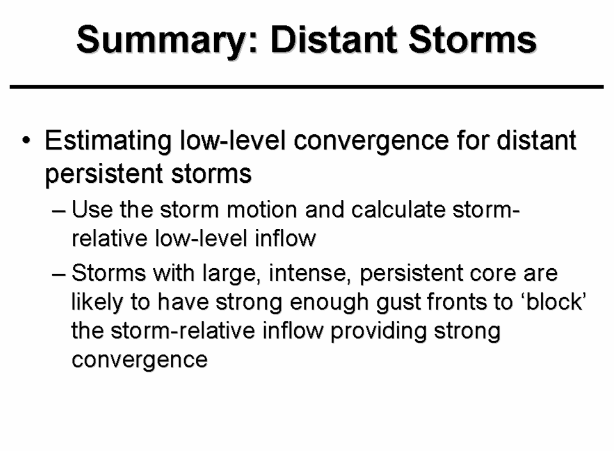
# 17. Summary: distant storms

**Instructor Notes:** Estimating low-level convergence from distant, persistent convective modes is a bit more problematic and relies on circumstantial evidence. Let's assume a cluster or supercell is moving along at a speed and has a large, intense core. As long as you can say this event has an intense gust front capable of forcing the storm-relative low-level inflow upward through convergence, you could use the forward motion of the storm and estimate its convergence as it moves into the low-level inflow. Be careful, it is hard to say what the storm-relative winds within the cold pool are when all you know is the storm motion.

**Student Notes:**



## Summary: Distant Storms

- Estimating low-level convergence for distant persistent storms
  - Use the storm motion and calculate storm-relative low-level inflow
  - Storms with large, intense, persistent core are likely to have strong enough gust fronts to ‘block’ the storm-relative inflow providing strong convergence