Evolution and Maintenance of the 22-23 June 2003 Nocturnal Convection

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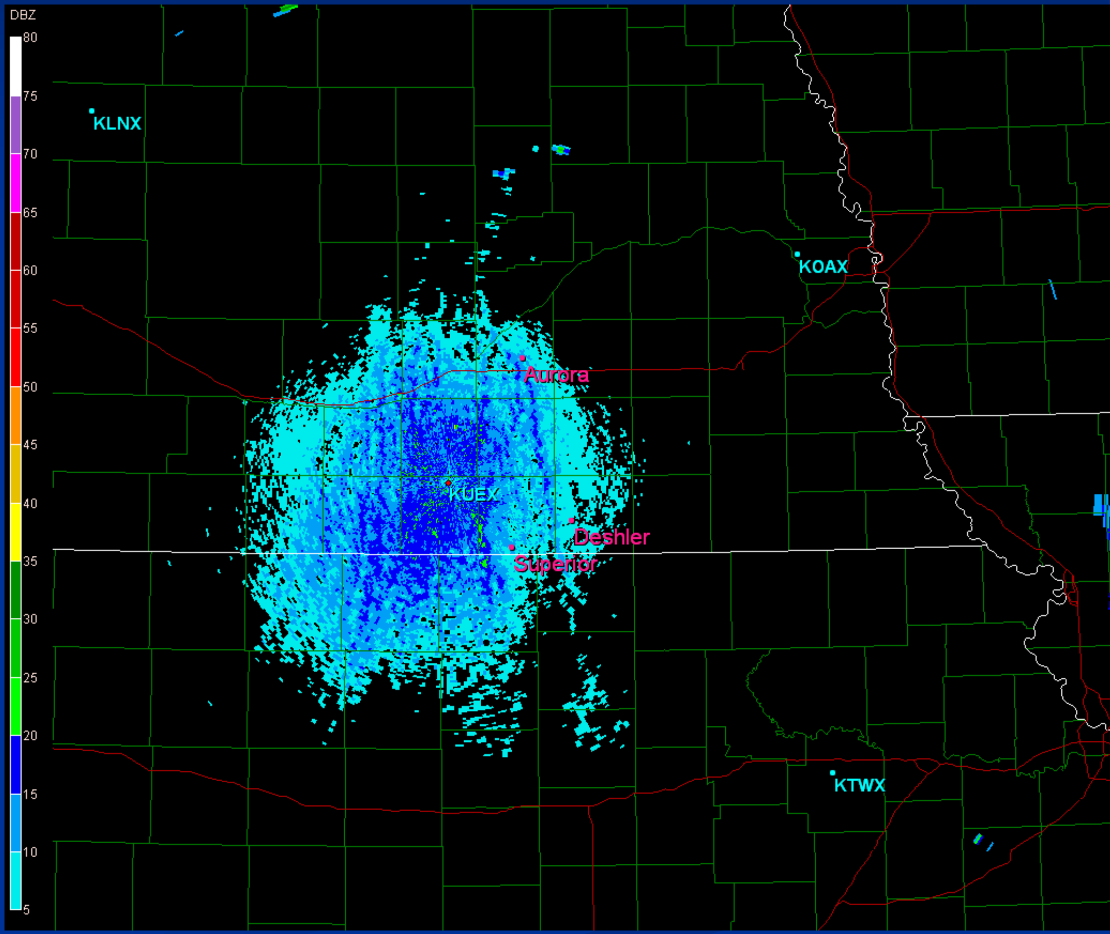
August 6th, 2011

† Work Completed at North Carolina State University for MS Thesis

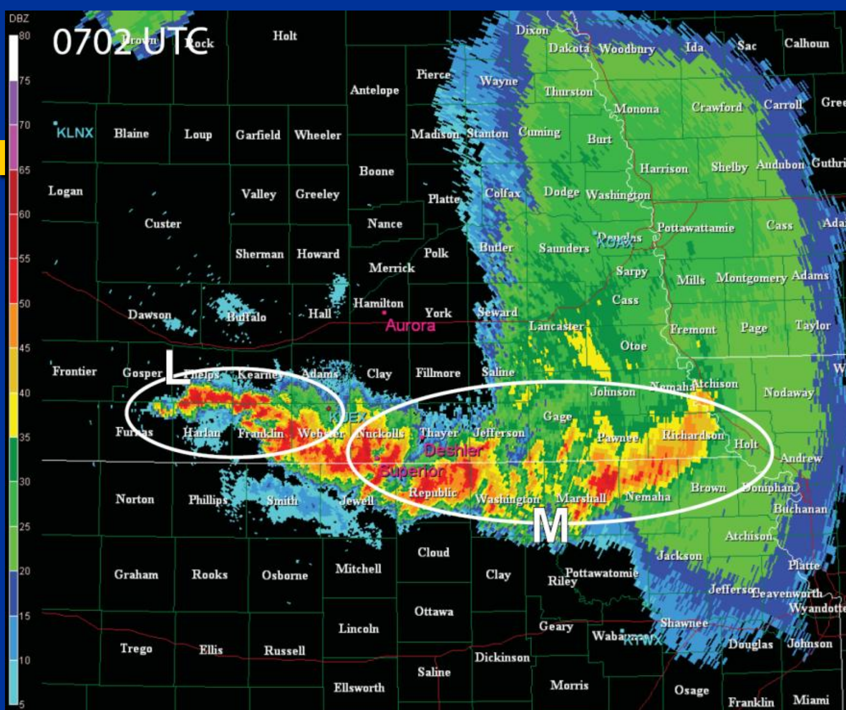
Introduction

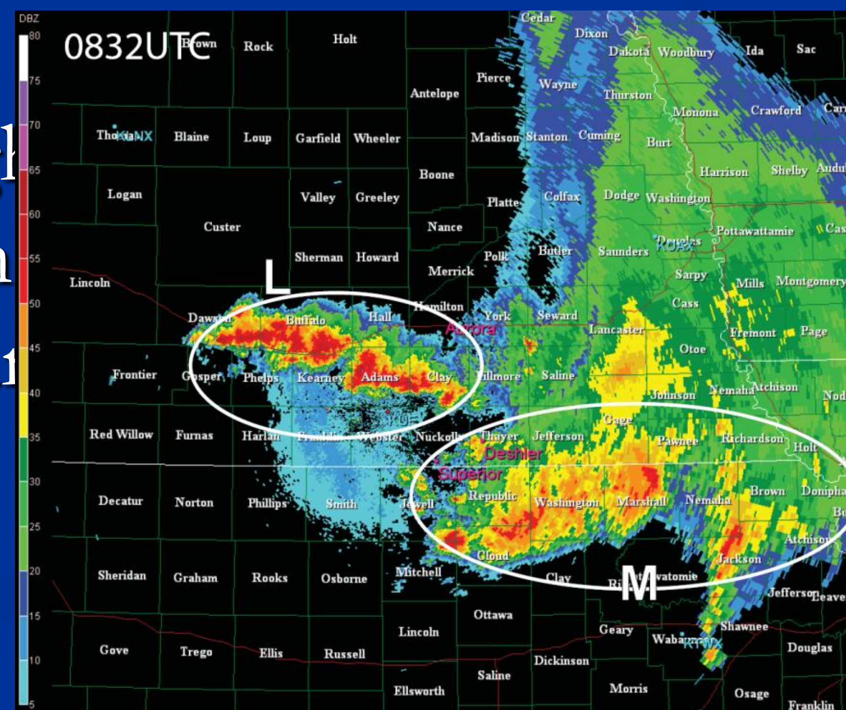
- During the evening and overnight hours on 22-23 June 2003, two different modes of convection coexisted in close proximity to one another.



Nocturnal Environment

- Southward propagating squall line
- Northeastward moving MCS





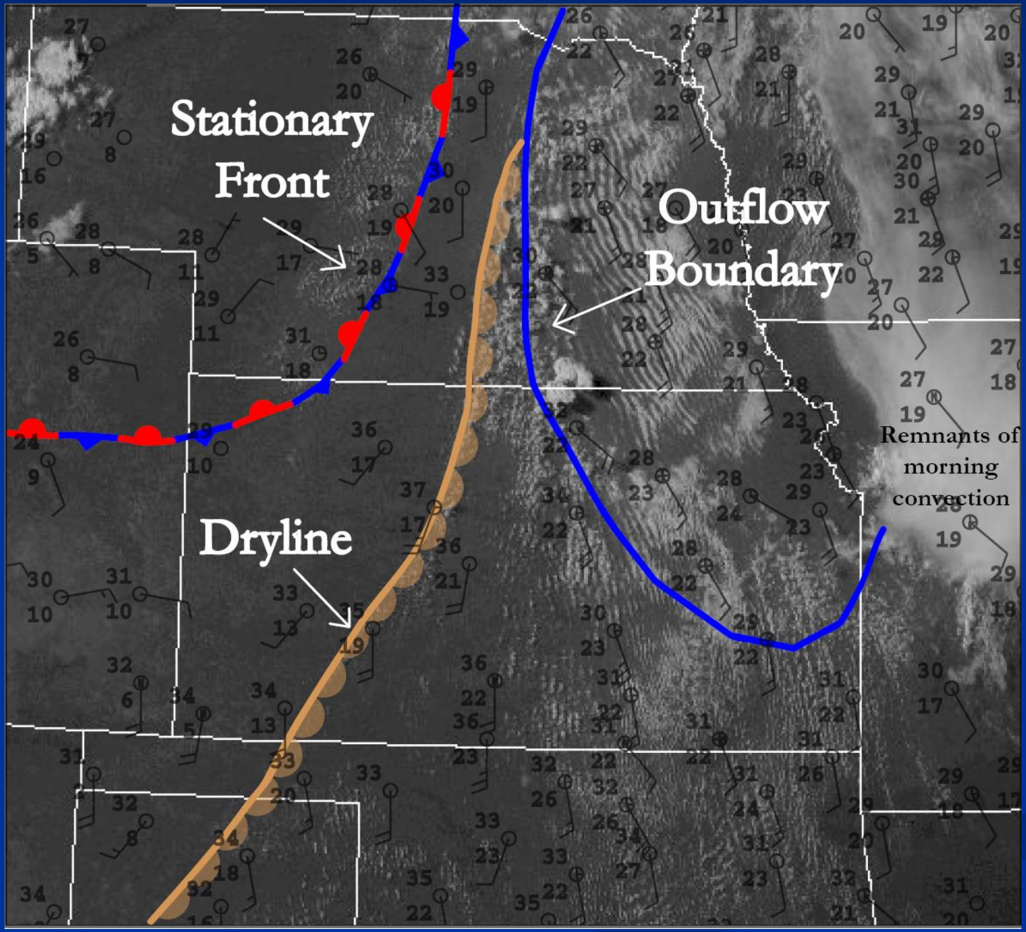
Nocturnal MCSs

- Convection associated with the LLJ is often believed to be elevated, in other words, it is thought to be maintained by feeding on air parcels located above the boundary layer.
- Recent studies by Bryan and Weisman (2006) and Parker (2007) have suggested that many nocturnal convective systems that were thought to be elevated are actually feeding on surface air, remaining surface-based.

Observational Results

Background Environment

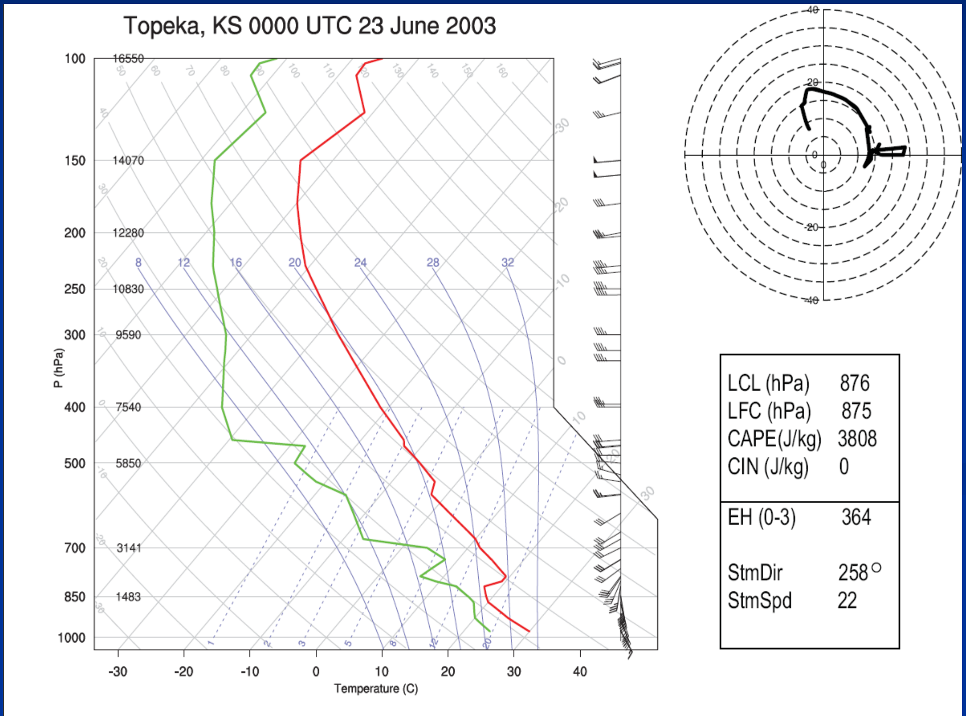
- Outflow from the mornings convection persisted into the late afternoon hours over
- Dryline
- Stationary front



Surface Boundaries valid at 2200 UTC

Background Environment

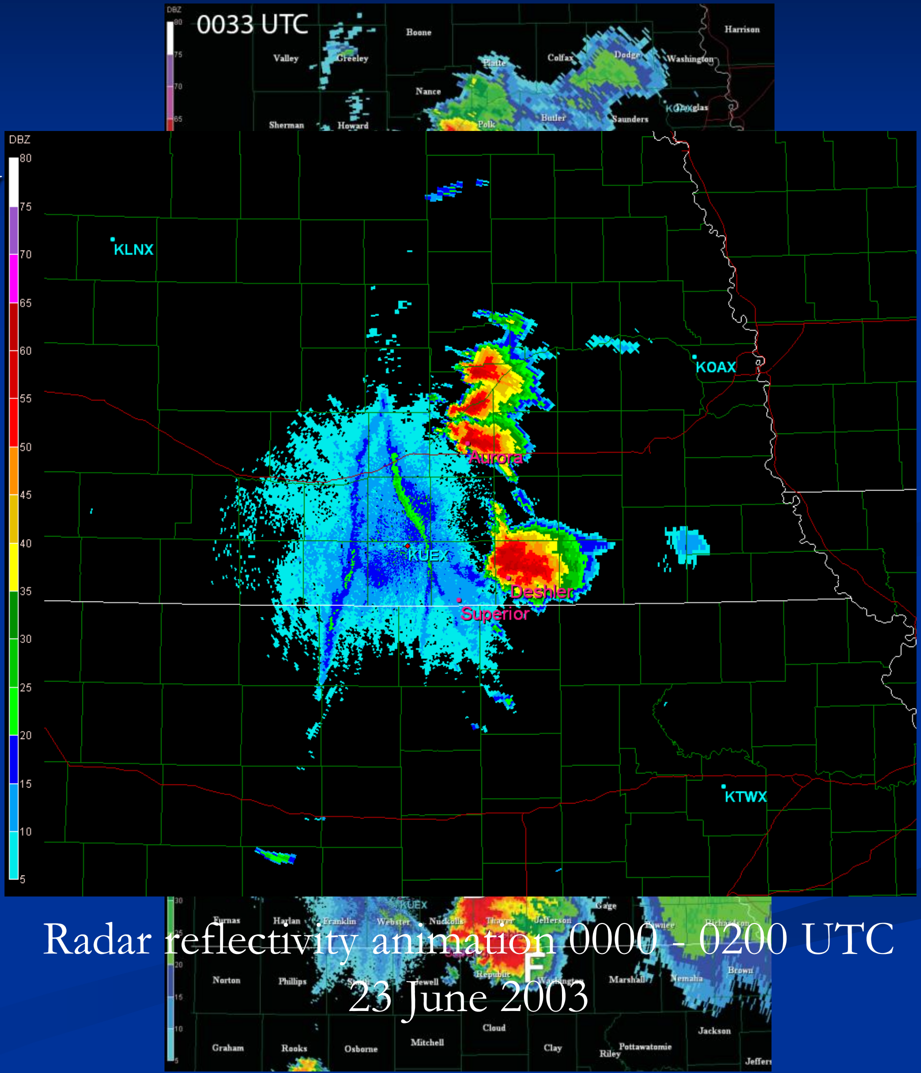
- The local environment was very unstable
- The 0000 UTC sounding from Topeka, Kansas
  - Convective available potential energy (CAPE) around 3808 J kg^{-1}
  - minimal convective inhibition (CIN)
- Curved hodograph supports supercell development



Above: Topeka, Kansas Skew-t and hodograph valid at 0000 UTC 23 June 2003

Storm Initiation and Storm mergers

- Storms initiated on the north-south orientated outflow boundary and quickly matured into supercells
- 6 individual storms merged with the Deshler Supercell changing its character. (3 of them C-E)
- Following these collisions, the superior supercell (storm F) developed and the collisions are hypothesized to enhanced the total precipitation mass which in turn lead to deeper lifting and a stronger cold pool

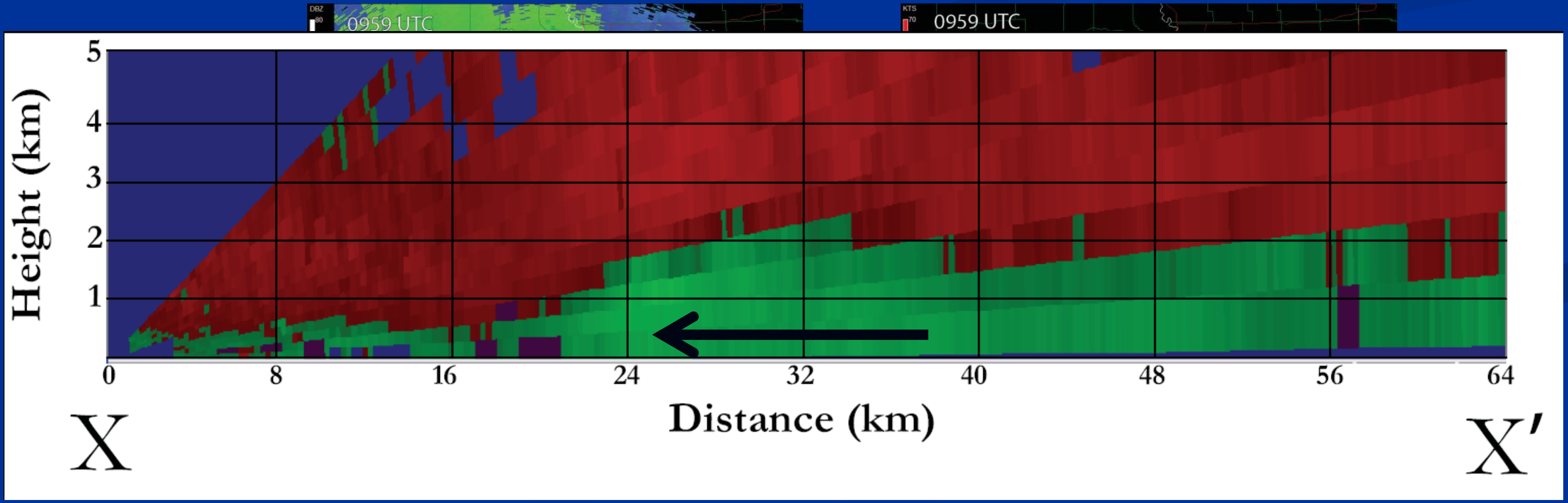


Radar reflectivity animation 0000 - 0200 UTC 23 June 2003

Radar reflectivity from KUEX at 0033 and 0208 UTC 23 June 2003

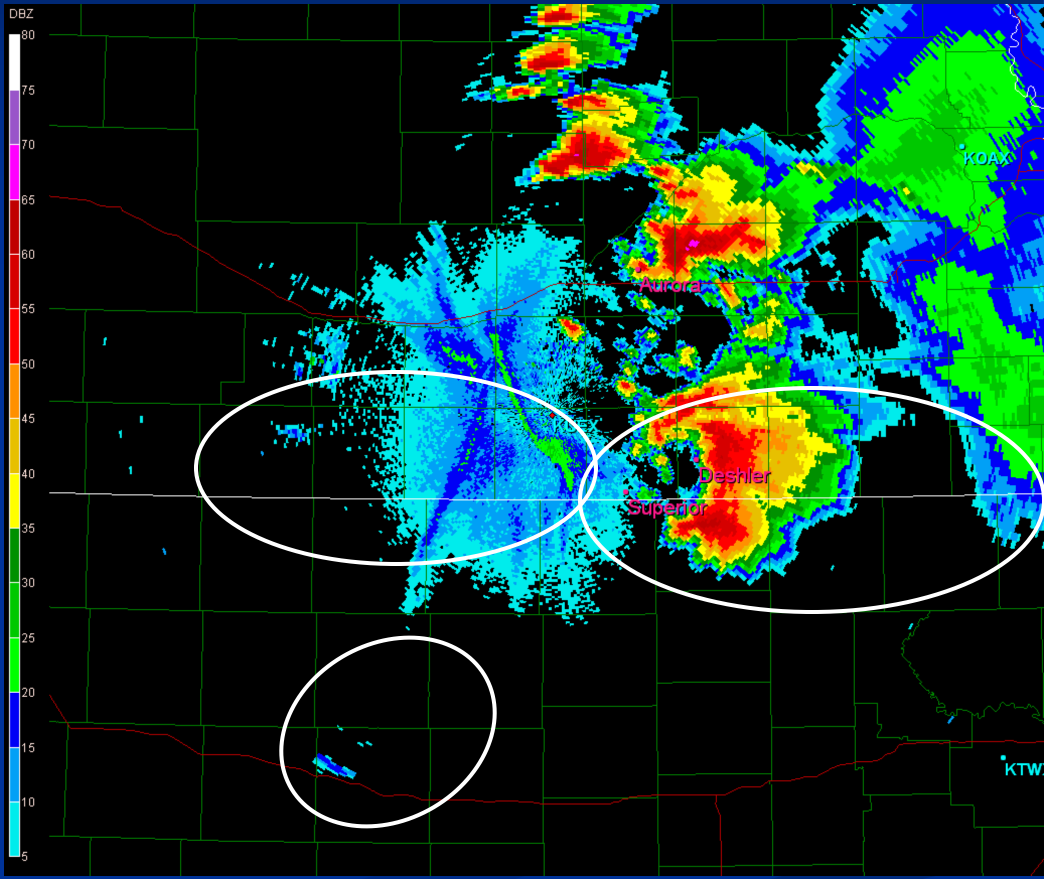
Cold pool at the surface

- Doppler Velocities from Topeka, KS at 0959 UTC show northerly winds associated with the cold pool



Evolution

- Isolated storms developed along the dryline in north central Kansas and moved northeastward
- The northeastward moving cells and the squall line existed nearby one another
- The western storms continued to move northeastward while the squall line continued to propagate slowly southward.



Observational Conclusions

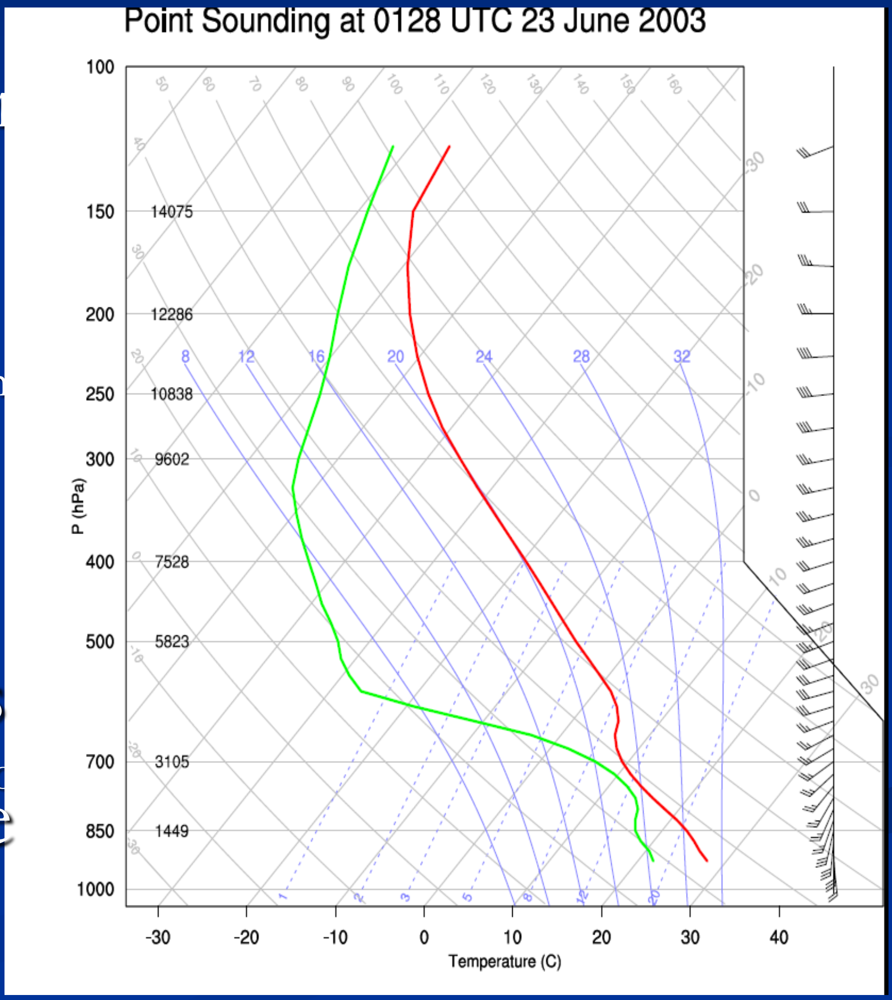
- Two modes of convection were present in close proximity to each other, suggesting that each mode was being forced differently or that their source layers were different.
  - The nocturnal squall line was surface-based
  - Still unclear whether the northeastward moving storms were either surface-based or elevated, and what mechanism was maintaining them.
    - Idealized simulations test the working hypotheses of whether or not these storms were surface-based or elevated.

Idealized simulation Results

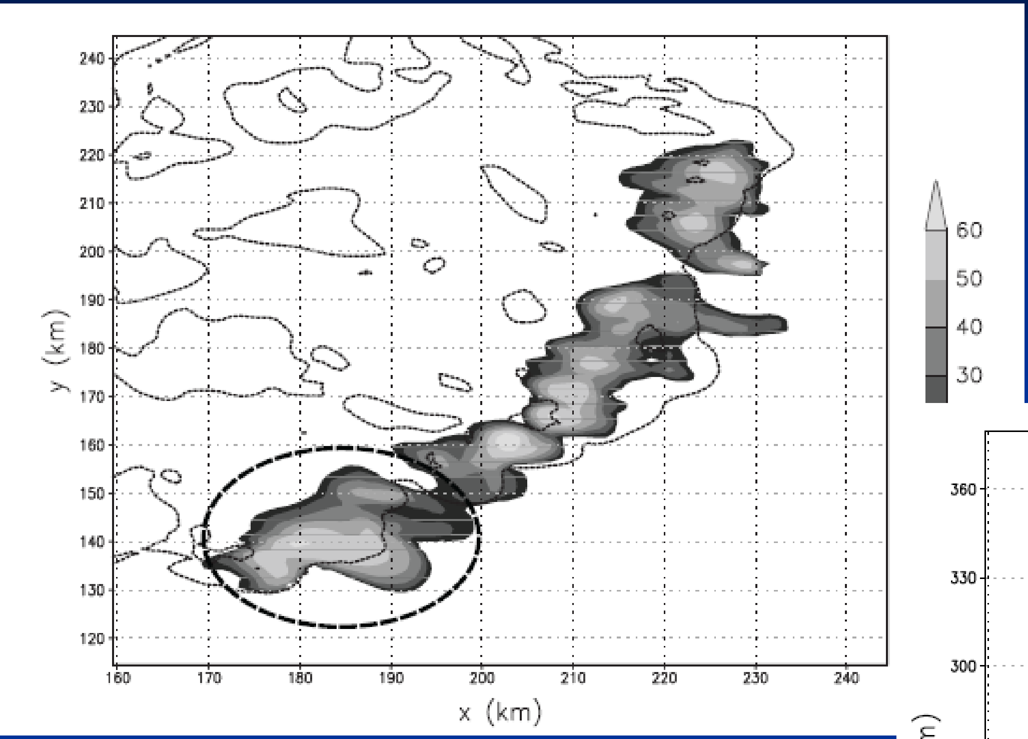
Idealized Simulations

- Idealized simulations
  - Using Cloud Model Version 1 (CM
  - 1 km horizontal grid spacing
  - Stretched vertical grid;
    - average grid spacing 350 m
    - 200 m in the lowest level to 500 m
  - Processes turned off:
    - Surface fluxes
    - Coriolis
    - Radiation
    - Homogeneous base state
  - Storm relative winds to keep the co domain

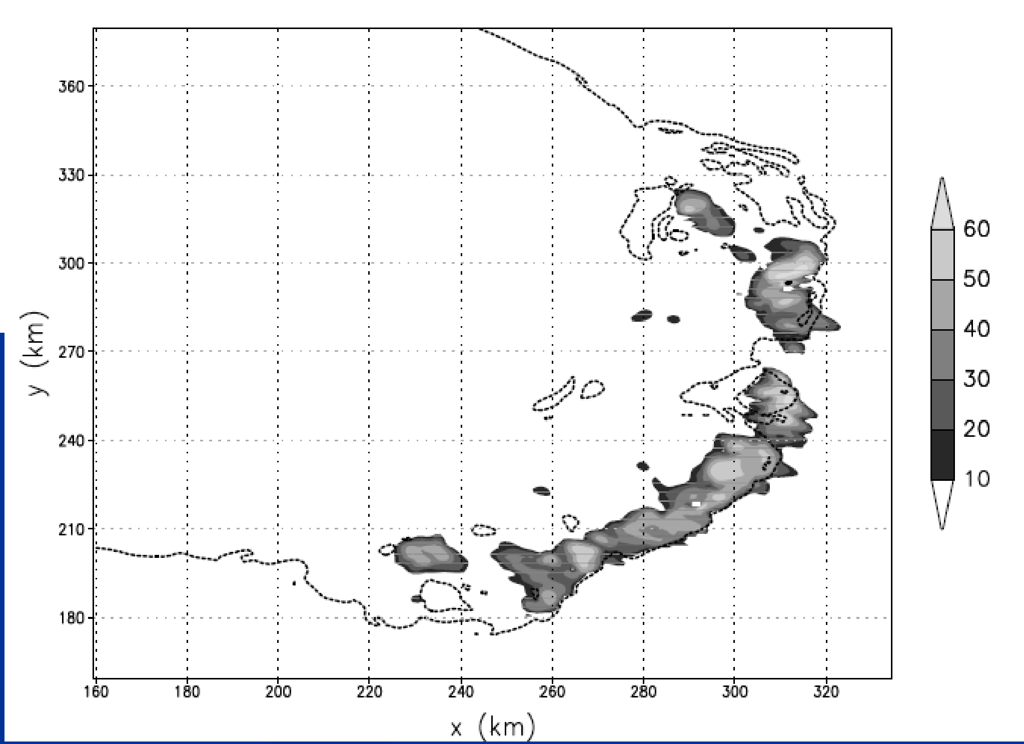
- Base state sounding
  - point sounding created from the case study simulation
- 4 different model setups
- Only showing 2 for time



First 2 Simulations



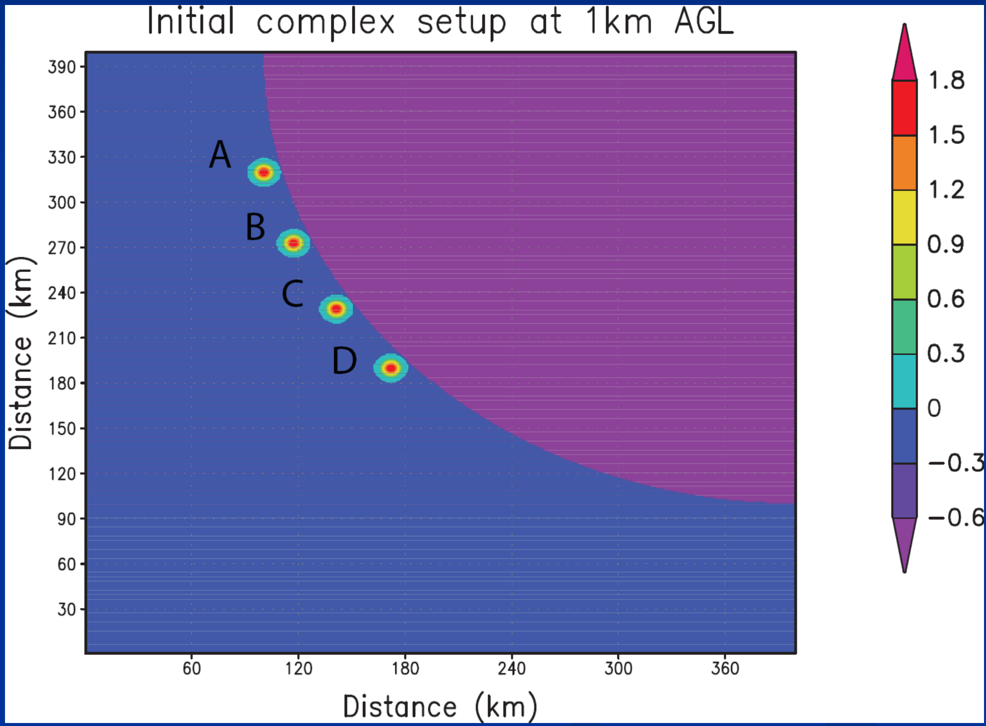
- Cold Pool



- Warm Bubble

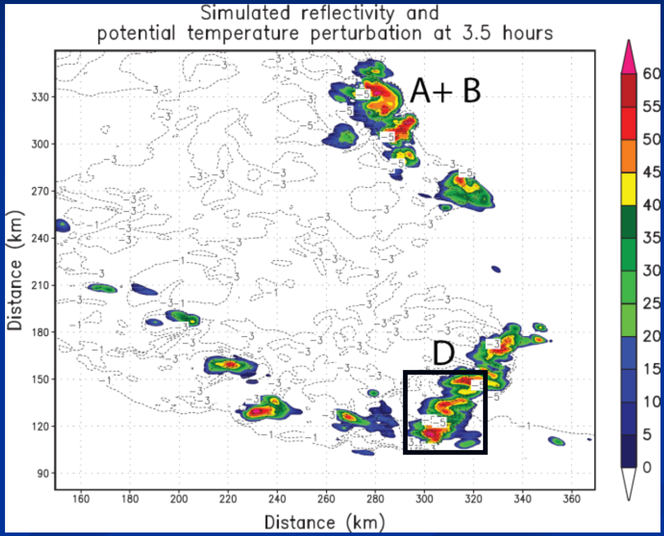
Outflow boundary setup

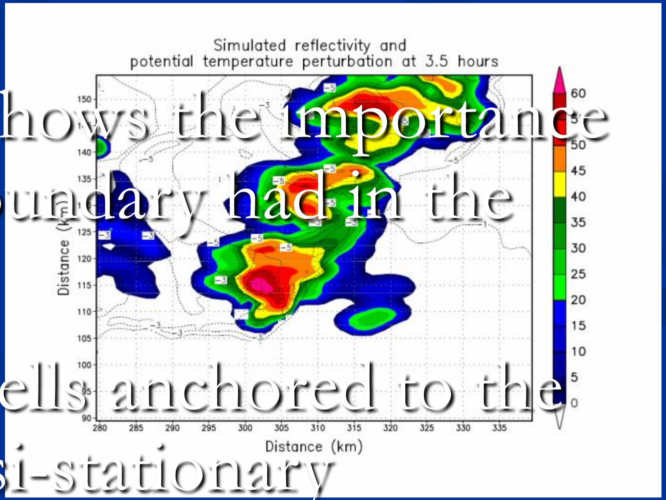
- "Complex" simulation
  - 600 x 400 km domain
  - 4 warm bubbles, quarter circle cold pool
  - -2 K cold pool, 3 K warm bubbles



Complex simulation

- Storms A, B and C moved toward the northeast
- Storm D anchored itself to the outflow boundary and moved along the cold pool toward the southeast
  - Ingesting high Θ_e air
  - Large amounts of storm relative helicity

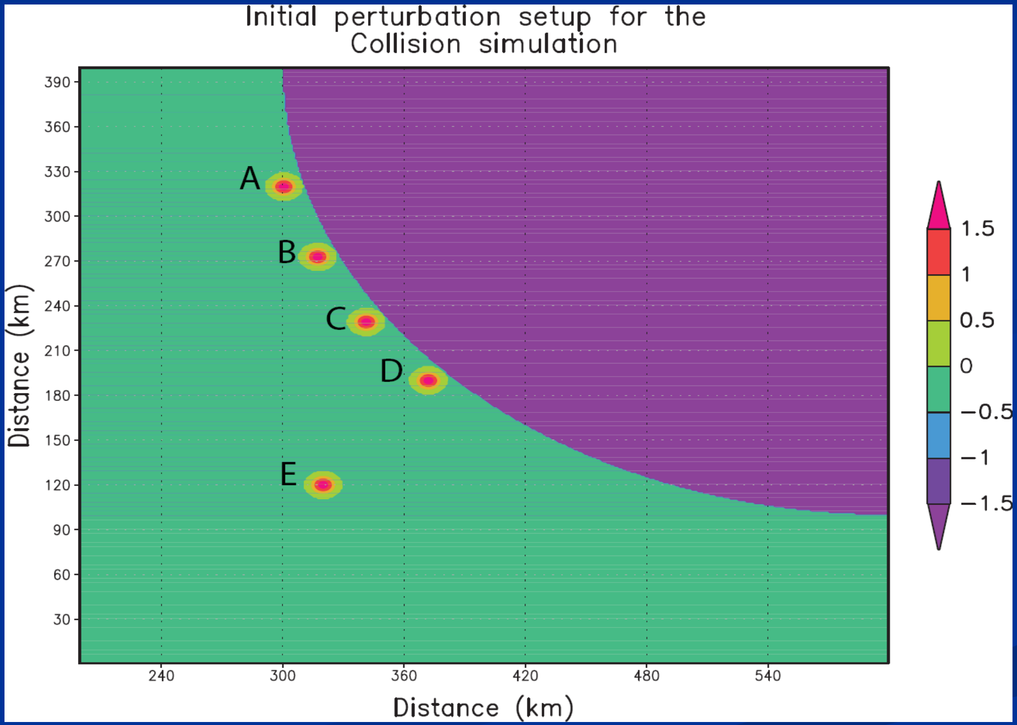




- The addition of the cold pool shows the importance that the pre-existing outflow boundary had in the observed case.
  - Deshler and Superior supercells anchored to the boundary and remained quasi-stationary

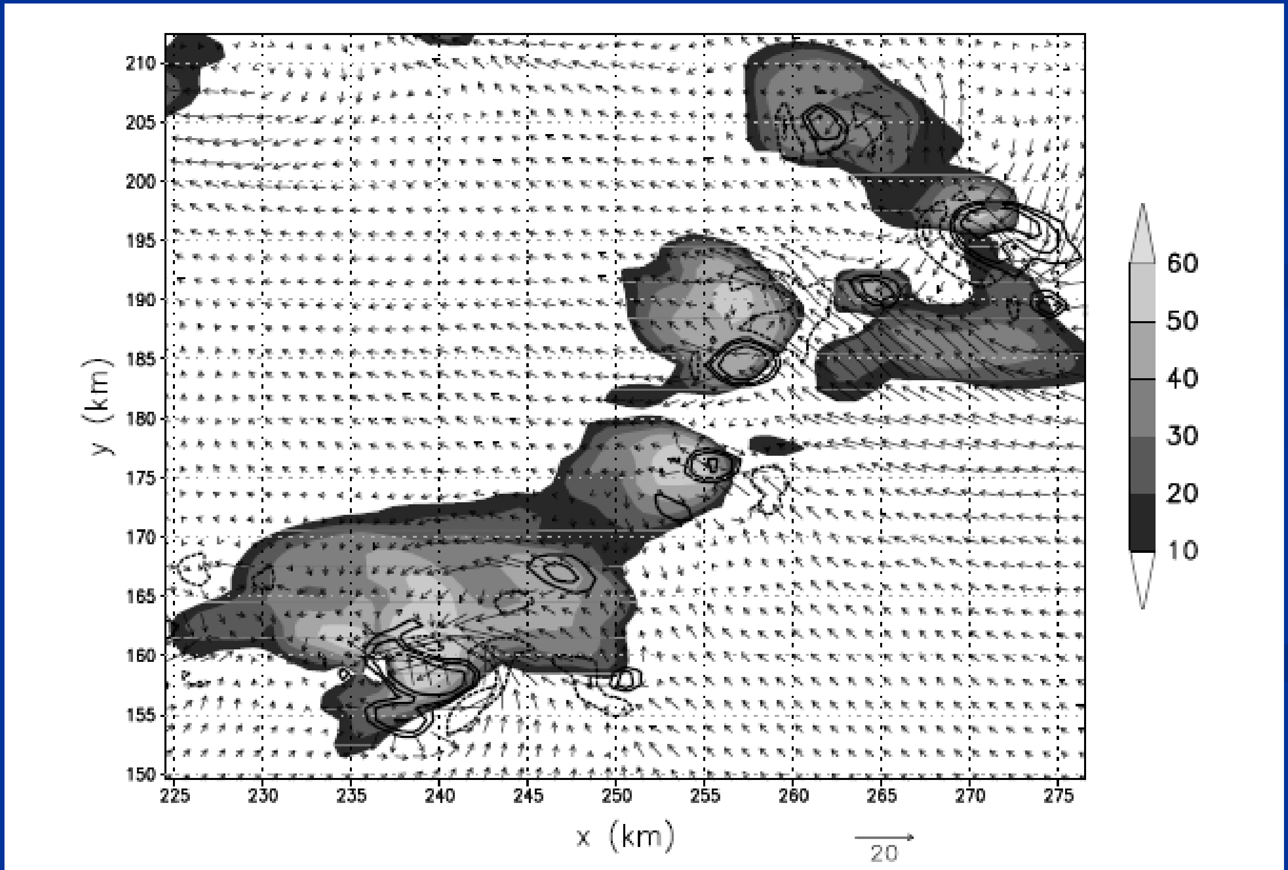
Merger Simulation Setup

- "Merger" simulation
  - 600 x 400 km domain
  - 5 warm bubbles, quarter circle cold pool
  - -5 K cold pool, 3 K warm bubbles



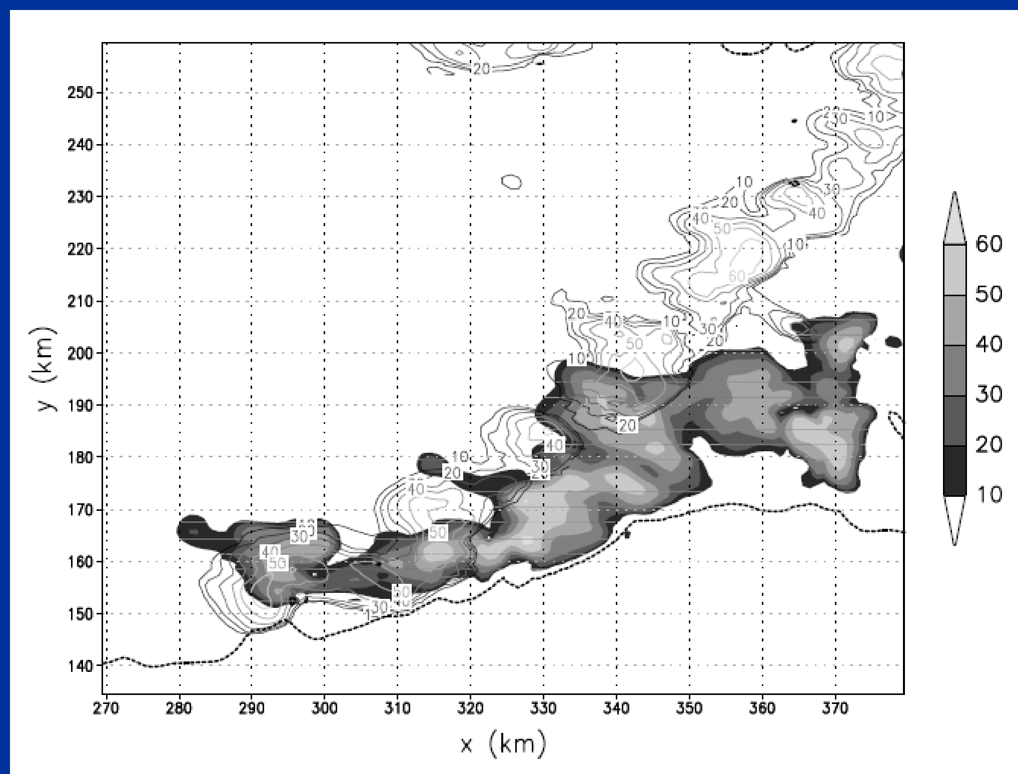
Merger simulation

- Storm E's left mover and storm D's right mover merged about 2 hours into the simulation



Subsequent Evolution

- This idealized simulation supports the hypothesis that the mergers were important in the reorientation of the observed squall line on 22–23 June.

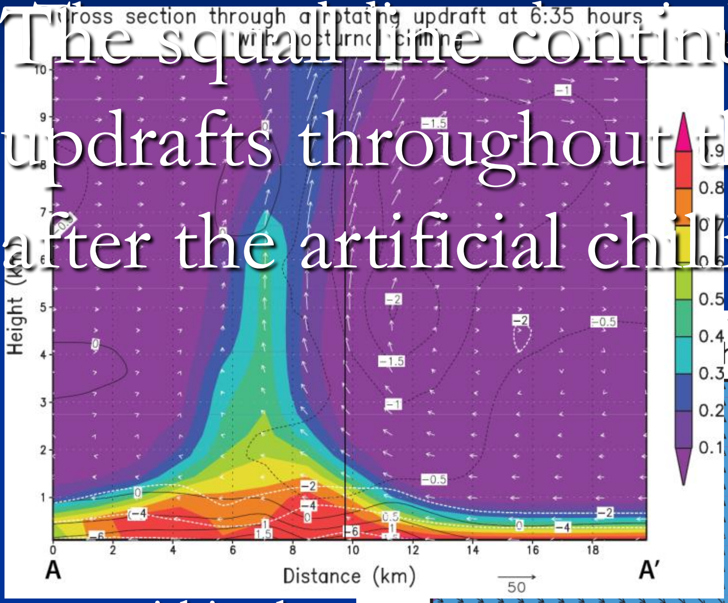


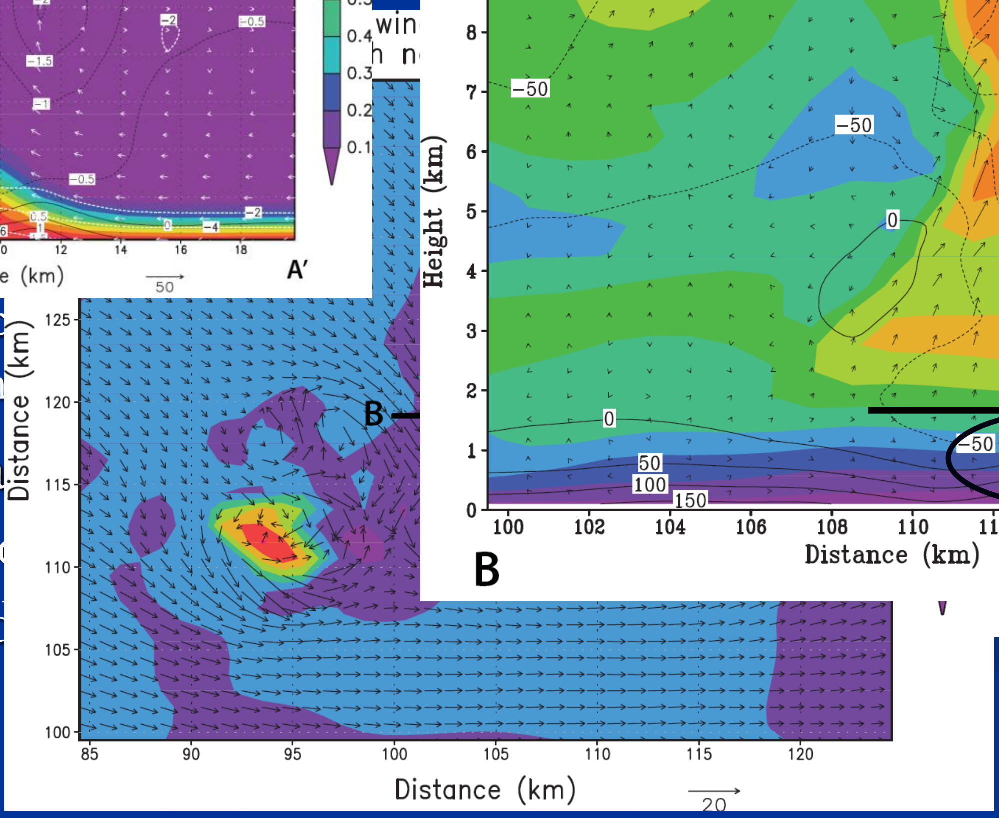
Add in Nocturnal influences

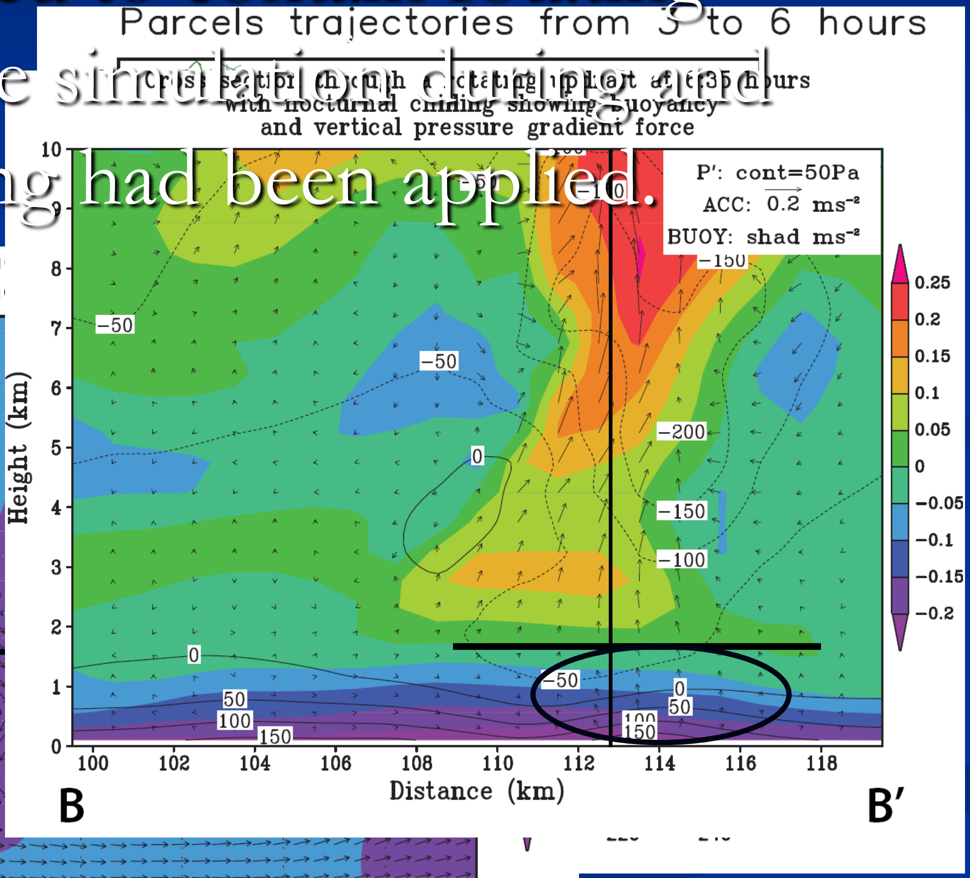
- Artificial chilling
  - Applied to the warm bubble and collision simulations
  - The lowest 1 km was cooled 5.5 C, similar to what was observed.

Effect of the chilling

- The squall line continued to contain rotating updrafts throughout the simulation during and after the artificial chilling had been applied.







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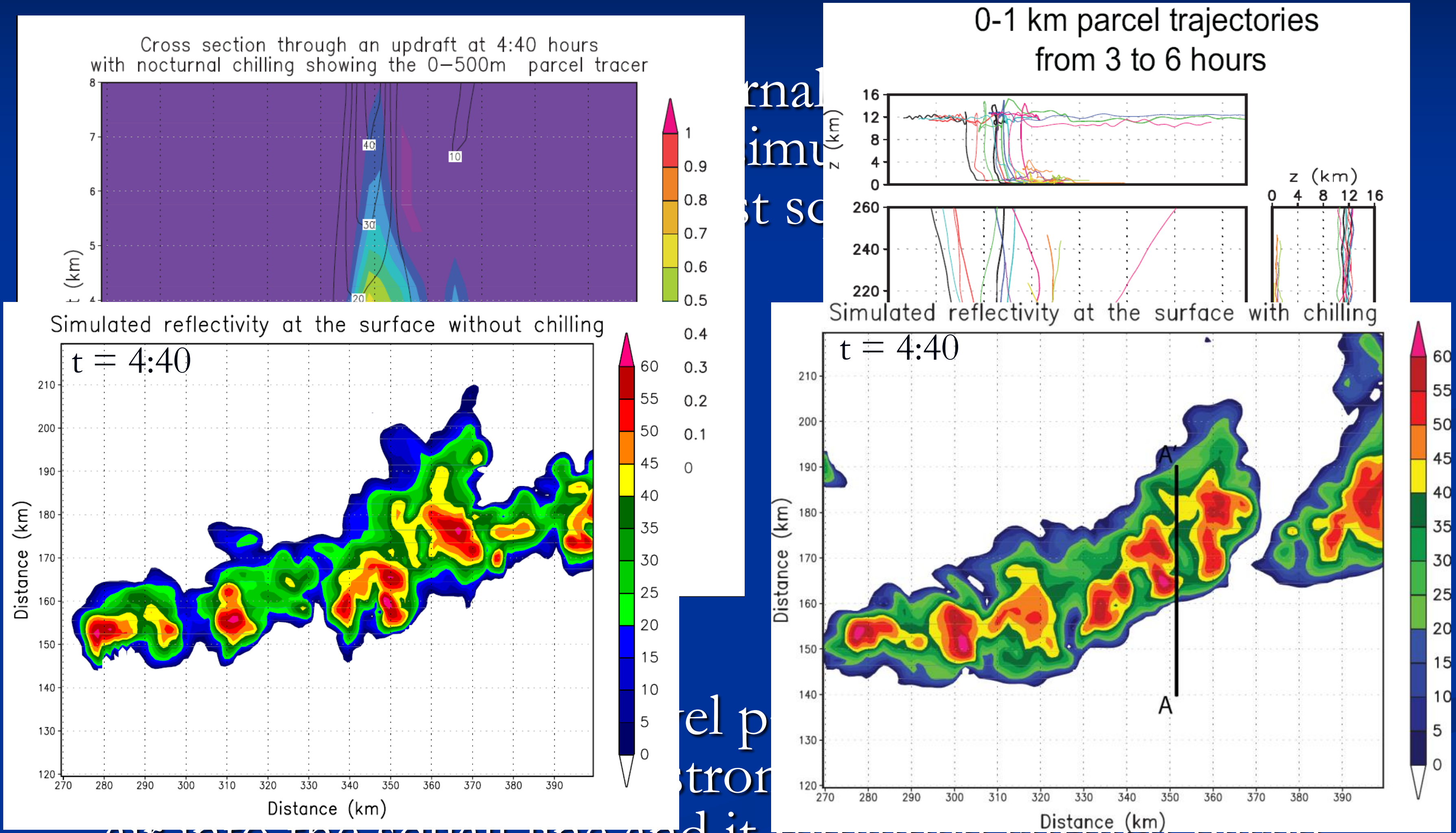
Nocturnal Merger simulation

- Artificial chilling and the Merger simulation
  - Chilling began at 3 hours
  - Chilling rate = 5 K/hour

Effect of the chilling on the merger simulation



air into the squall line and it remained surface-based.

Conclusions

- The observed supercells developed along a pre-existing outflow boundary.
- Storms and outflow mergers were fundamental to the reorientation of the system into an east/west squall line.
- Supercells were initiated along the dryline in north-central Kansas. These storms moved northeastward throughout the event due to the southwesterly mean cloud-layer wind.
- As the boundary layer cooled during the night, two distinct storm modes persisted.

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Acknowledgments

- Advisor: Dr. Matthew Parker
- Committee: Dr. Gary Lackmann, and Dr. Sandra Yuter
- Convective Storms Group members; Adam French, Ben Baranowski, Billy Booth and Adam Baker
- Family and Friends
- National Science Foundation Grant ATM-0552154

- Extra slides

Simple forcing: warm bubble

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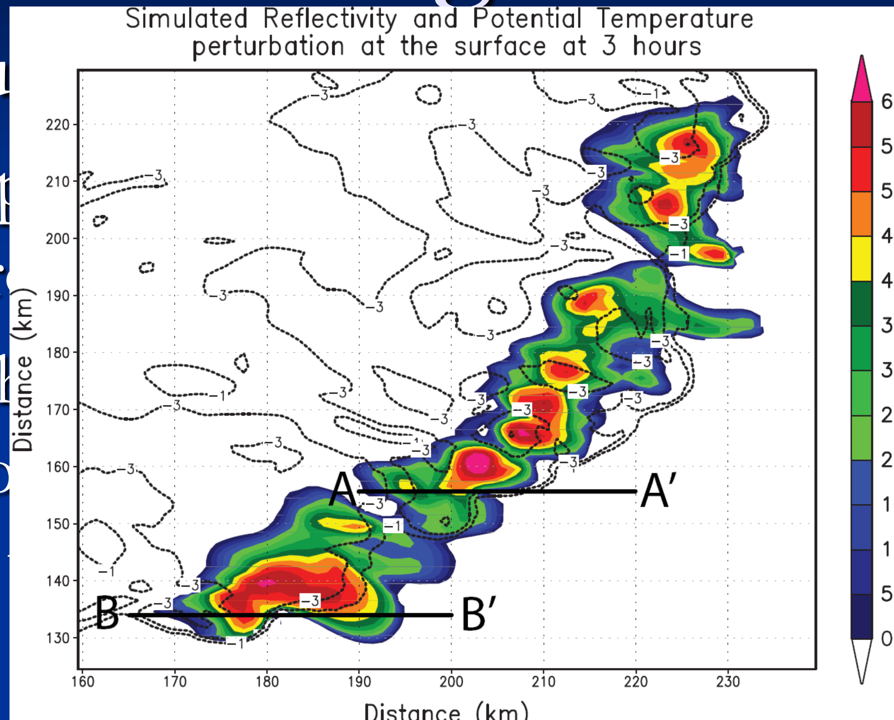

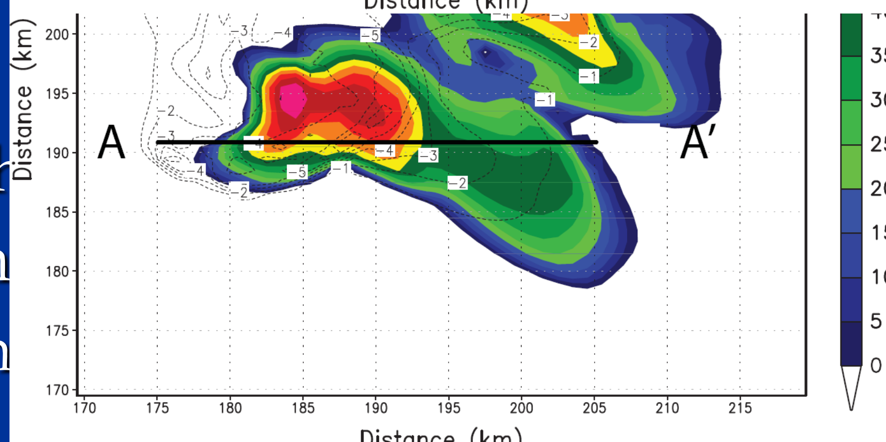

Simple forcing: warm bubble

- Similarities to observed
  - Splitting
  - Northeastward motion
- Without a pre-existing outflow boundary, new storms simply developed on the downshear side of the simulated system's cold pool.

Simple forcing: cold pool

- Cold pool
  - Convection developed along the downshear (eastern-southeastern side) of the cold pool
  - The remnant cold pool present on 22 June, suggested some similarities with the initial cold pool trigger
  - However, the storms developed long the southwestern side of the cold outflow, which was not the downshear side
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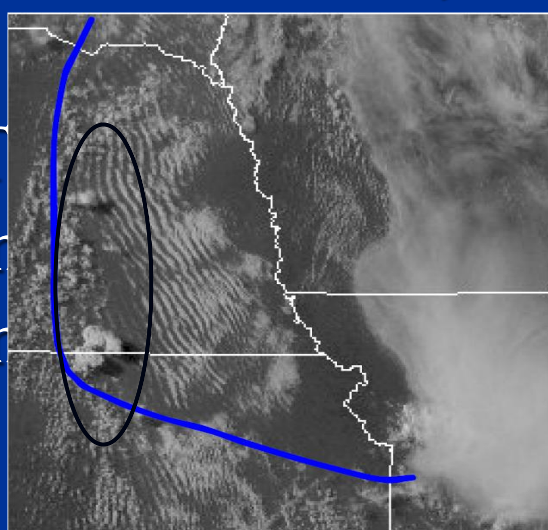
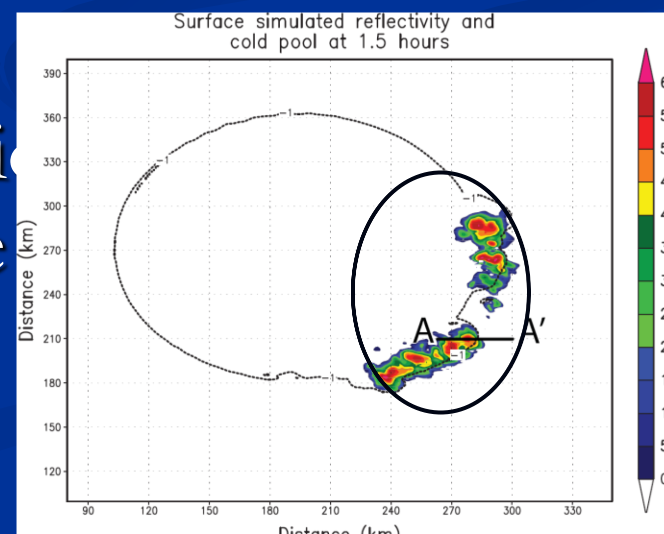
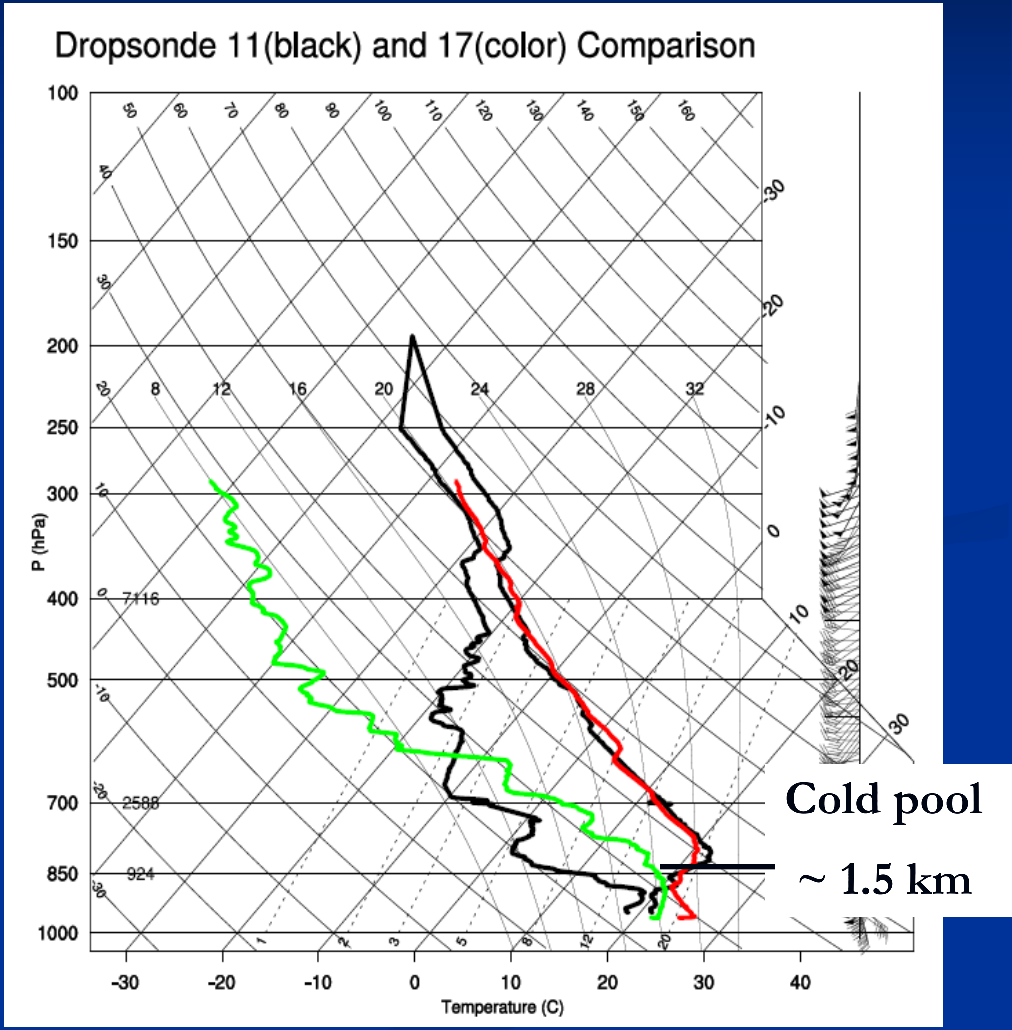




Cold pool depth

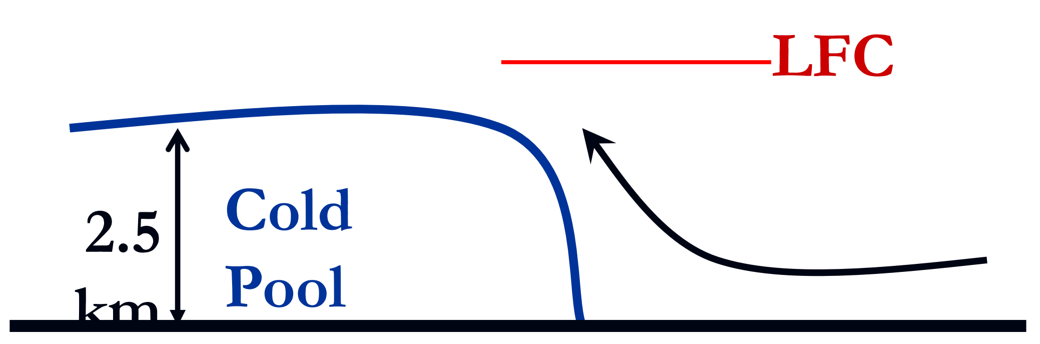
- The level of free convection (LFC) ahead of the squall line was approximately 2.5 AGL (dropsonde 17)
- Cold pool depth from dropsondes ~ 1.5 km.



Comparison of Dropsonde 11 (behind convection) and Dropsonde 17 (ahead of convection)

Surface-based squall line

- Surface observations in Kansas reveal that the squall line continued to possess a surface cold pool well into the nighttime hours
- A deep cold pool would be necessary for the squall line to ingest the surface air



Idealized flow over a cold pool

Surface-based squall line

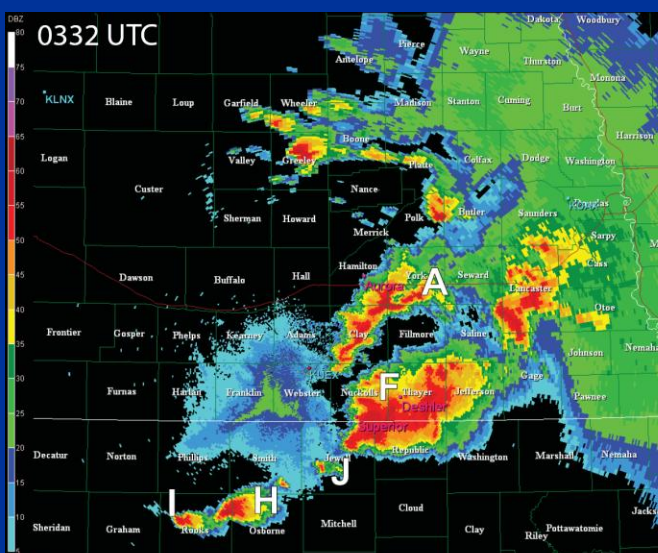
- Parker (2007) showed that a symptom of elevated squall lines is "under flow", in which surface air does not acquire its LFC and simply passes under the convective region which does not appear to be the case on 23 June: no underflow regime was evident from the surface observations or radar velocities
- Therefore evidence shows that the squall line remained cold pool – driven, explaining the southward storm motion throughout the nocturnal hours, and explains the southward propagation in an environment with prevailing southerly flow.

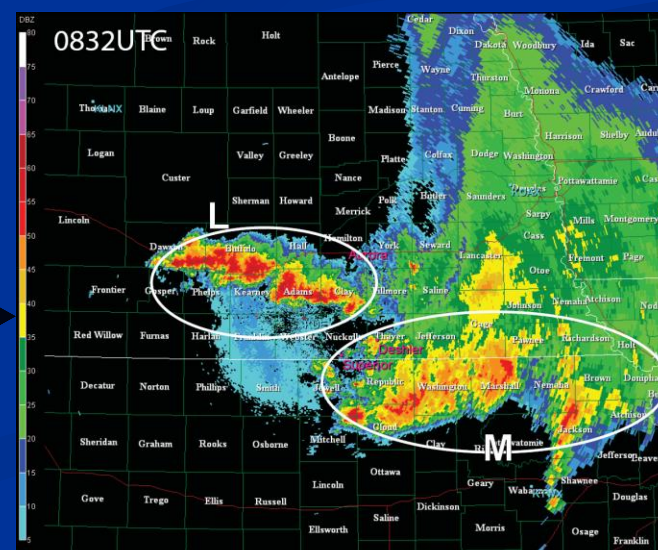
Two modes of convection in a similar environment

- These two modes of convection (supercells and squall line) were seemingly one system at times.
- Even though they appeared to share a common leading edge, they were being maintained by different forcing mechanisms
- Explaining their differing motion vectors

Subsequent Evolution

- Isolated storms developed along the dryline in north central Kansas and moved northeastward (storms H and I)
- The northeastward moving cells and the squall line existed nearby one another (storms L and M)
- The western storms (L) continued to move northeastward while the squall line (M) continued to propagate slowly southward.





Discussion

- Two MCSs developed during the evening and overnight hours on 22-23 June 2003.
  - Southward propagating squall line
    - Initial supercells initiated in a north-south line along the pre-existing outflow boundary
    - Storm mergers created quasi-stationary supercells that evolved into a southward moving east-west oriented squall line.
  - Northeastward moving storms
    - Isolated storms developed in north central Kansas and moved northeastward
    - Eventually developing into a small MCS and continuing to move northeastward throughout central Nebraska

Key processes

- Pre-existing outflow boundary
  - Orientation of the initial supercells
  - Acted to anchor storms, deviating from the mean northeastward storm motion
- Cell mergers
  - Enhanced precipitation production
  - Stronger cold pool
- Reorientation of the system into an east-west squall line
    - Strong cold pool at the surface remained deep enough throughout the night to maintain surface-based convection

Key processes

- Two modes of surface-based nocturnal storms
  - Surface-based cold pool-driven squall line
  - Surface-based northeastward moving storms via dynamically induced pressure force associated with the mesocyclone.
- As long as storms contained rotating updrafts they continued to ingest surface-based air