The Effects of Anvil Shading From a Nearby Squall Line on the Structure and Evolution of a Discrete Supercell Thunderstorm

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Introduction

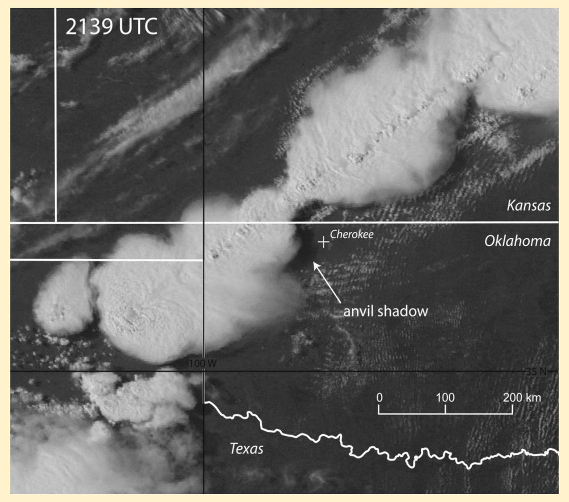

Figure 1: Visible satellite imagery illustrating anvil shading ahead of an approaching squall line (Figure from Bryan and Parker, 2010).

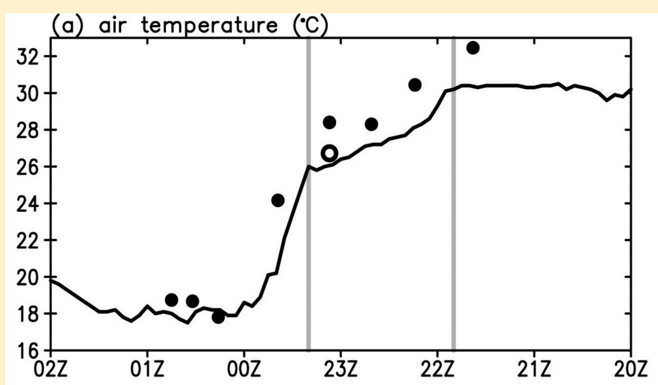

Figure 2: Time series of surface temperature observations associated with the squall line shown in figure 1. The cooling associated with anvil shading is shown between the vertical grey lines (Figure from Bryan and Parker 2010).

- Optically thick cirrus anvils are a common feature of convective storms, including squall lines and supercell thunderstorms.
- "Anvil shading" results from a reduction in solar radiation beneath the cirrus anvil and leads to cooling of 3-6K of the near surface layer.
- This cooling can lead to reduced instability for convective storms, and changes in low-level vertical wind shear via reduced boundary layer mixing.
- Recent modeling studies have illustrated that the evolution of both supercell and squall line thunderstorms can be affected by shading from their own anvil, however results were sensitive to storm motion relative to the anvil.

Given that supercells and squall-lines are often observed in close proximity during severe weather outbreaks, the present research seeks to understand how anvil shading ahead of a squall line may affect a supercell that is present in this region.

Model Configuration & Methods

- Four simulations were run using version 1.18 of cloud model CM1 (Bryan and Fritsch. 2002):
  - "COMBINED" runs include squall line and supercell.
  - "SOLO" runs only include discrete supercell.
- All simulations include short- and long-wave radiation and surface fluxes.
  - "CLEAR" simulations treat cloud as transparent
  - "SHADED" simulation include cloud radiative effects.
- All simulations use the NASA-Goddard version of the Lin et. al. (1983) ice microphysics scheme.
- The horizontal grid spacing was 500 m and the vertical grid stretched from 50 m near the surface to 250 m aloft.

Model Runs	Combined Clear (**CC**)	Combined Shaded (**CS**)	Solo Clear (**SC**)	Solo Shaded (**SS**)
Anvil Shading	Off	On	Off	On
Convective Storms	Squall Line & Supercell	Squall Line & Supercell	Supercell only	Supercell Only

Table 1: Summary of model runs.

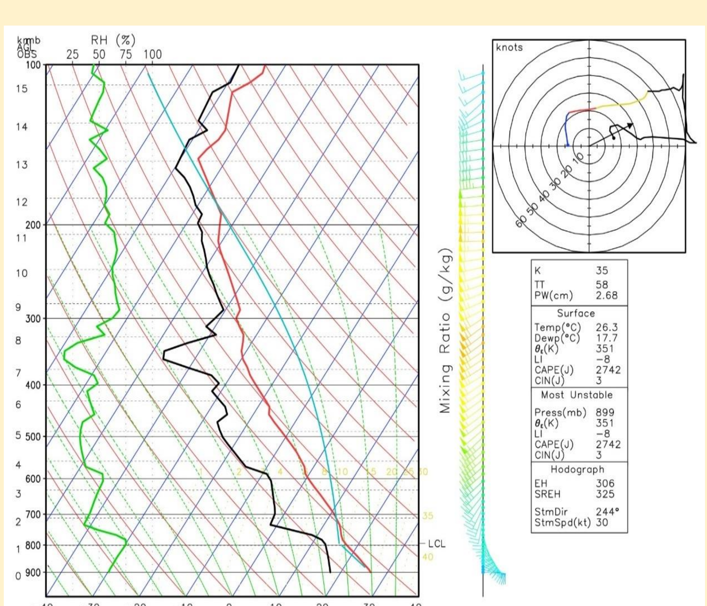

Figure 3: Skew-T Log-P diagram and hodograph illustrating initial temperature and moisture soundings and wind profile used for all simulations. Sounding is based on a proximity sounding from a squall line/supercell event from 24 May 2008.

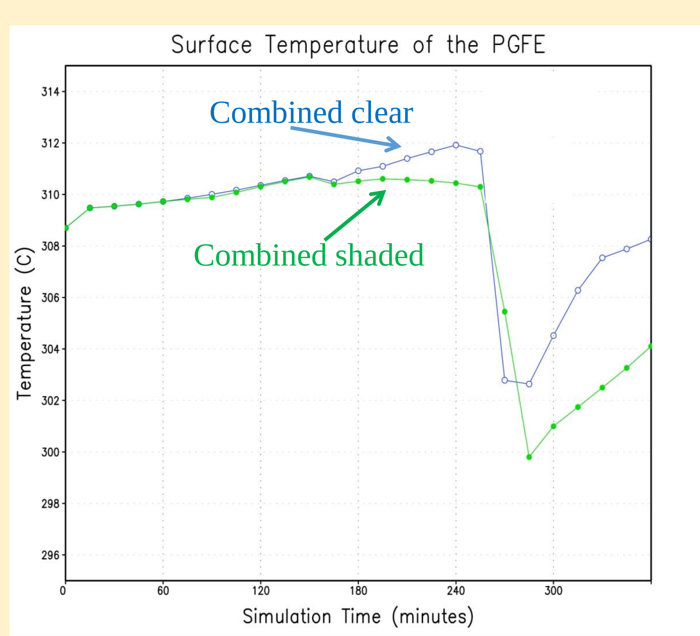

Figure 4: Surface temperature trace ahead of squall line in COMBINED CLEAR (blue) and COMBINED SHADED(green) simulations. Anvil shading beings at approximately 1500 LST.

Overview of Model Simulations

- All simulations sustained similar supercells through approximately 2 hours of run-time.
- All storms show a cyclical evolution in updraft intensity, and low level vertical vorticity.
- Around 150 minutes into the simulations, the updrafts in each run begin to weaken.
- Three of the runs re-intensify within 30 minutes of this weakening; the CS simulation weakens further and dissipates by 225 minutes simulation time.
- The onset of this weakening occurs when the shading from the squall line overtakes the supercell in the CS simulation.

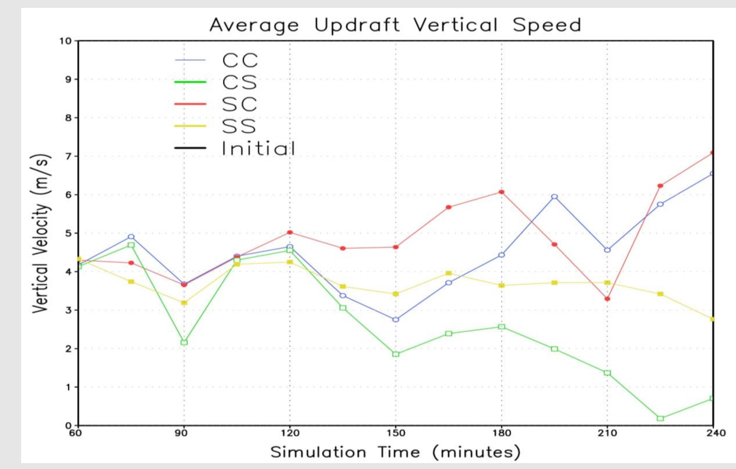

Figure 5: Time series of average updraft speed associated with the supercell in the combined clear (blue), combined shaded (green), solo clear (red) and solo shaded (yellow) simulations.

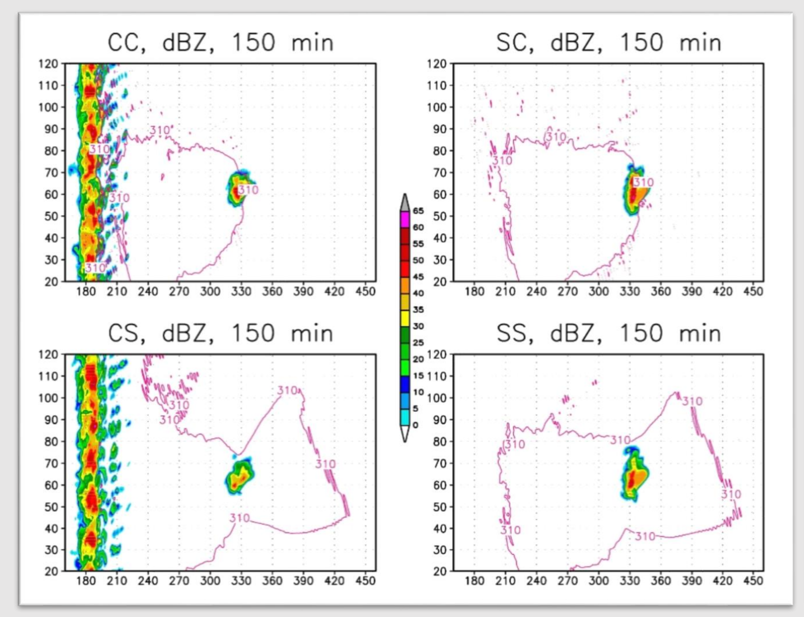

Figure 6: Simulated radar reflectivity (shaded, dBZ) and surface 310 K potential temperature contour (K). For (a) combined clear, (b) solo clear, (c) combined shaded and (d) solo shaded simulations at 150 minutes into the simulation. The 310 K potential temperature contour approximates the outline of the anvil shading from both the squall line and supercell.

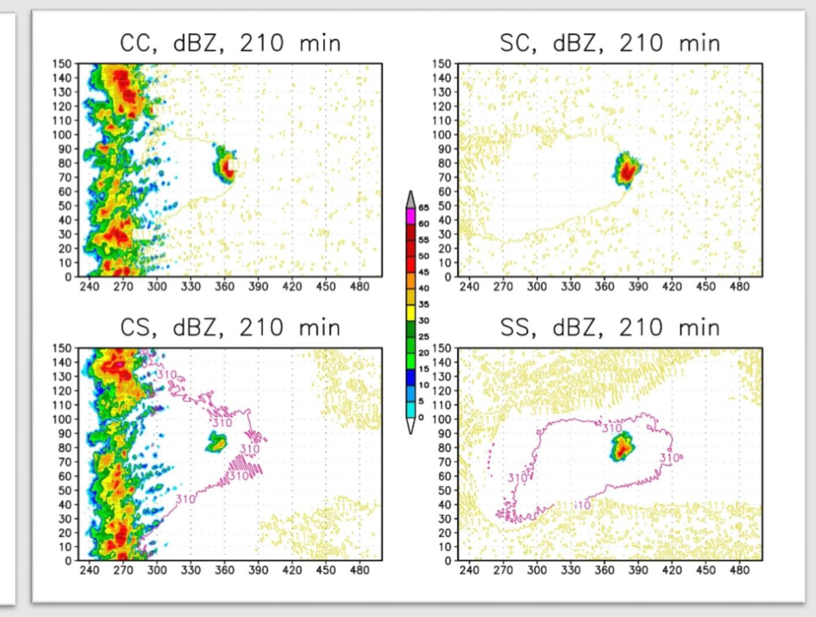

Figure 7: As in figure 6, but at 210 minutes into the simulations and including the 311 K surface potential temperature contour as well to denote anvil shading.

Evolution of Inflow CAPE & Shear

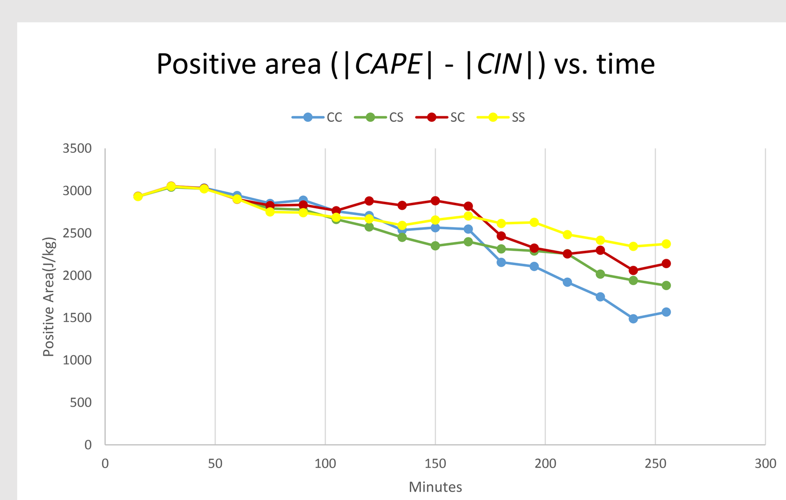

Figure 8: This chart of the positive area versus time shows the average positive area of a 10 x 10 km area in the inflow of the supercell, southeast of the storm's updraft. Runs ranked in order from highest to lowest positive area: Solo Shaded, Solo Clear, Combined Shaded, Combined Clear.

- Over the inflow region positive area was reduced more for the COMBINED cases than for the SHADED cases. This suggests a larger effect related to the presence of the squall line than from its anvil shading. Eventually, larger reductions in positive area were seen for the CLEAR cases than SHADING, presumably due to deeper boundary layer mixing.
- Overall, changes were small and inflow CAPE values remained larger than 1000 J kg^{-1}, suggesting that changes in buoyancy were not responsible for the dissipation of the COMBINED SHADED supercell.

- The wind profiles of the inflow (Figure 9a) show a reduction in low-level wind speed in the SHADED runs, but the low-level shear profiles are comparable to the CLEAR simulations. The shading from the squall line alone appears to have little effect on low-level shear.
- The wind profile of the shaded area ahead of the supercell (Figure 9b) shows slower surface winds for SHADED runs, leading to stronger easterly shear. This is consistent with past research.

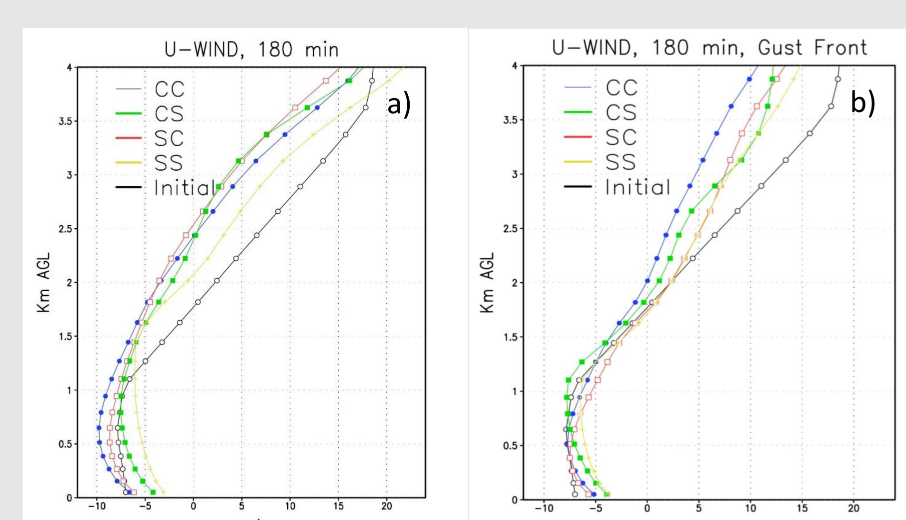

Figure 9: Average u-wind profiles at t= 180 minutes for (a) a 10 x 10 km area of the inflow, and (b) a 10x10 km area in the shaded region of the supercell. Approximate regions are shown as grey boxes in figure. 9.

Evolution of the Updraft and Gust Front

- Supercells in all four simulations exhibit a cyclical behavior whereby the gust front periodically cuts off the updraft, and a new updraft develops.
- One such cycle begins in all four runs at approximately 120 minutes. The two clear skies runs and the solo shaded run all cycle as usual, however the COMBINED SHADED does not complete the cycle as the gust front continues surging ahead, cutting off the storms' inflow leading to its ultimate demise.
- A likely cause of this evolution is the stronger low-level *easterly* vertical wind shear within the shaded region ahead of the supercell in the COMBINED SHADED run.
- Reduced heating beneath the anvil in SHADED runs leads to suppression of vertical mixing, so that the surface friction only decelerates winds in the few lowest model levels (Frame and Markowski 2010).

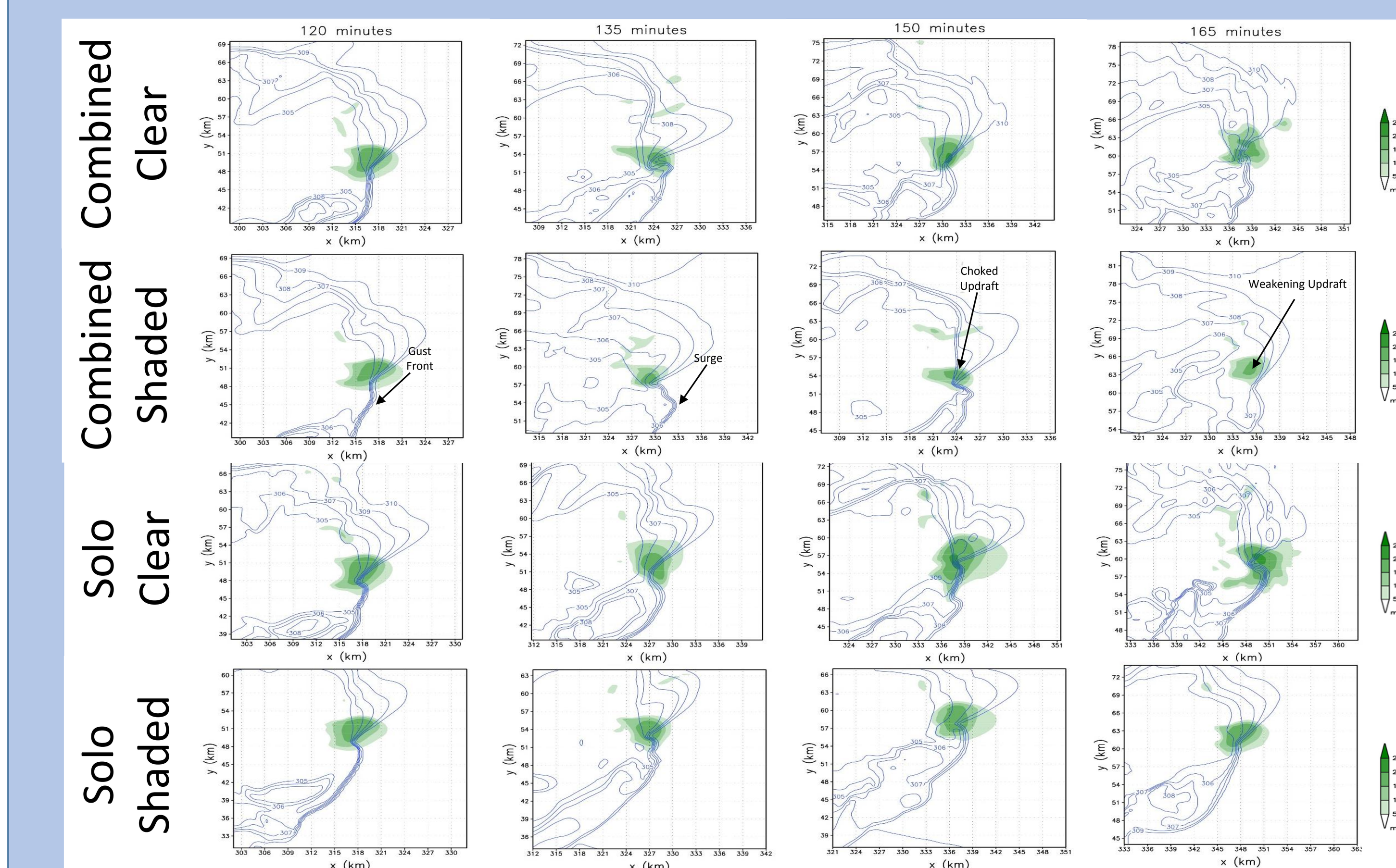

Figure 10: The updraft (shaded green) is plotted over potential temperature (dark blue) contours. These are shown at fifteen minute intervals beginning at 120 minutes and ending 45 minutes later.

Storm Motion

- COMBINED supercells travelled more to the north than SOLO supercells. We hypothesize that this change in path is due specifically to the approaching squall-line.
- COMBINED SHADED supercell changes direction substantially at 120 min., leading it farthest north.
- This change in direction is associated with a weakening in the updraft.
- The latitude, longitude, and time of day cause the strongest shading to be northeast of the supercell (combined effects from supercell and squall line).

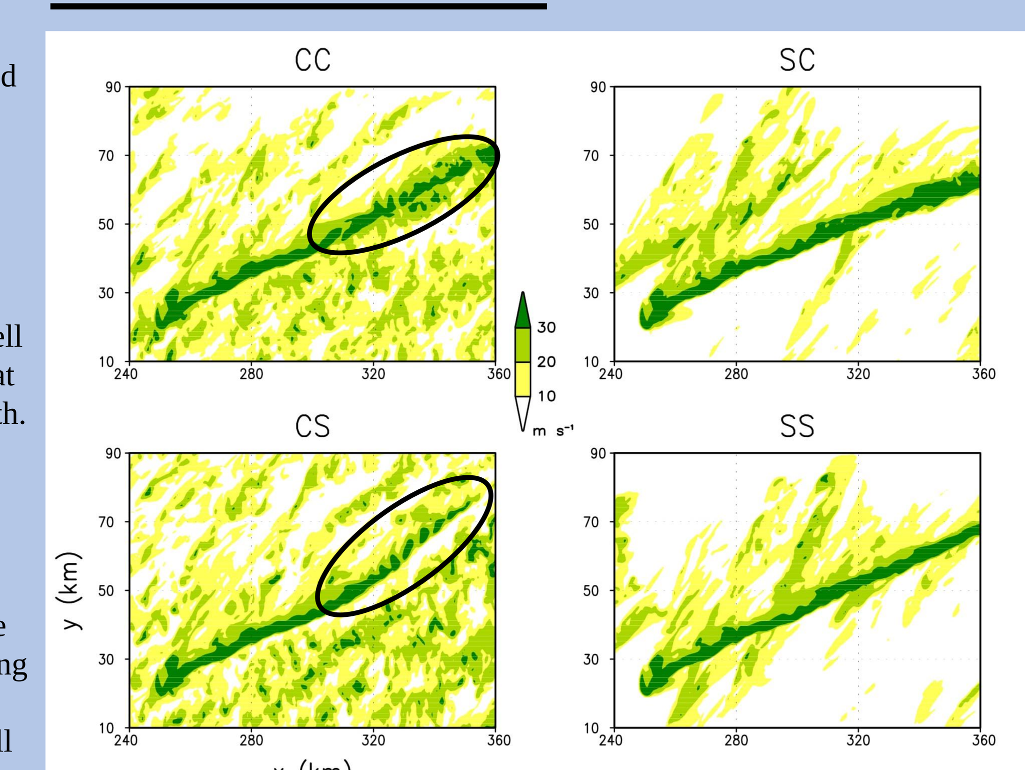

Figure 11: Max vertical velocity at 3 km AGL accumulated over time for all grid points for (a) combined clear, (b) solo clear, (c) combined shaded, and (d) solo shaded. This essentially shows the path of the supercell (in dark green, where vertical velocity is above 30 m/s).

We hypothesize that the squall line's approach induces subtle changes in direction, and that this causes the COMBINED SHADED supercell to move into the region of strongest shading, leading to its demise.

Future Work

- Quantify role of changes in wind shear in gust front evolution in COMBINED SHADED case.
- Determine process responsible for changes in storm motion seen in the COMBINED cases. What is the role of the approaching squall line in this evolution?
- Examine the sensitivity of these results to vertical grid spacing in the model.
- By varying either the strength of the shading or the speed of the supercell, investigate whether more cooling leads to quicker storm dissipation.

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