Observations and Simulations of Miniature Supercells[1,2]

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Part 1: Case Study

Single Doppler radar observations were made of a supercell in Shackleford County Texas on 19 February 1994. The supercell storm produced a tornado and extensive wind damage near Albany, Texas. The tornado life cycle occurred within 20 miles of the WSR-88D at Moran, Texas. *The supercell was remarkable for its diminutive size. While it displayed some of the well known radar characteristics of supercells, the storm top did not exceed 9 km MSL and the storm diameter was on the order of 5 km.* The rapid evolution and small size are consistent with a hypothesized class of supercell storms responsible for a number of tornado events in the southern and eastern United States. *Thus, this case study and the simulation contribute to the identification and classification of an important class of supercell storms which may be responsible for a large number of severe weather events.*

Part 2: Idealized Simulation Study

Numerical simulations of miniature supercells (MS) using a three-dimensional nonhydrostatic cloud model (Wicker & Wilhelmson 1995) were done in order to analyze the dynamical character of the storms and to determine in what types of environments they might occur. Soundings having CAPE values ranging from 600 to 2000 J kg^{-1} were used in environments having low to high wind shear (from 0.004 s^{-1} to 0.008 s^{-1}).

Model Parameters

- 50x50x15 km domain
- 1 km horizontal resolution.
- Stretched vertical resolution (0.3 km at ground to 0.5 km above 5 km)
- Kessler Microphysics

Case Study Sounding

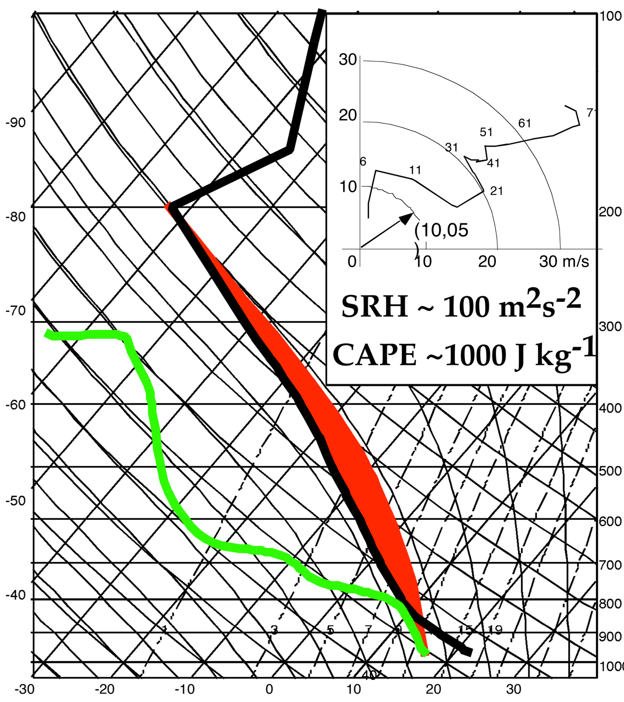

Figure 1 The input model sounding adapted from the 0000 UTC 20 February 1994 Stephenville, Texas sounding. Modifications were made at low levels to incorporate the temperature and dew point observed near Abilene Texas prior to storm development.

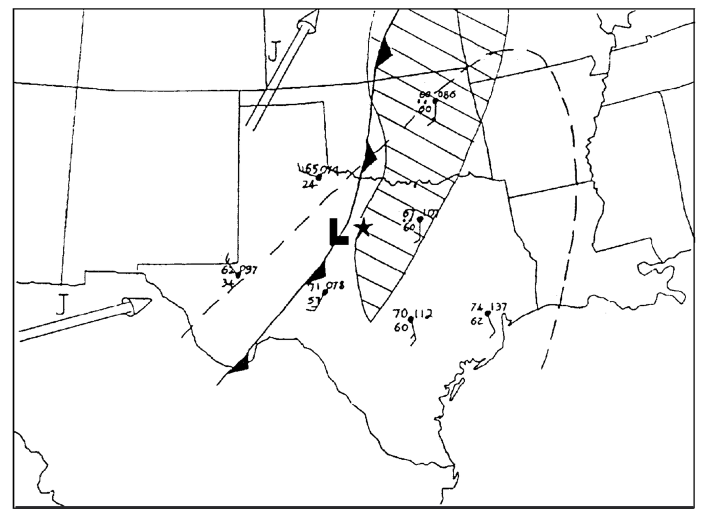

Figure 2 Composite 1200 UTC upper air and 2000 UTC surface analysis for 19 February 1994. Stations are plotted by convention. The barbed line is the surface cold front. The hatched area covers the region where 850 mb winds greater than 25 m s^{-1}. The dashed line encloses the 700-500 mb temperature lapse rates greater than 20 C, and the "J" arrows represent the 250 mb jet streaks. The star indicates storm location.

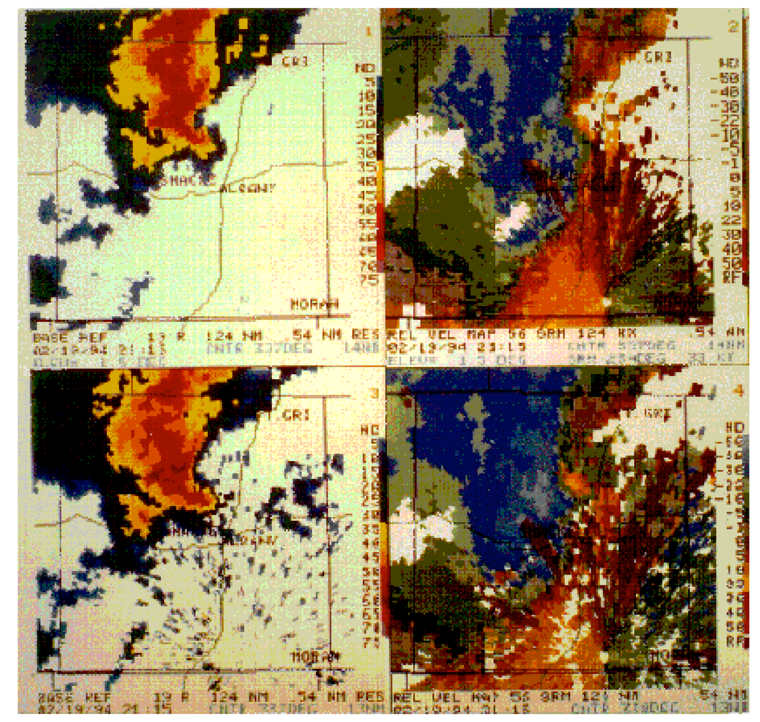

Figure 3 The 2115 UTC WSR-88D Doppler radar picture from Dyess Air Force base showing the supercell during its tornadic phase. On the left is reflectivity at 0.5 and 1.5 degrees elevation. On the right is the single Doppler storm-relative velocities at the same elevations.

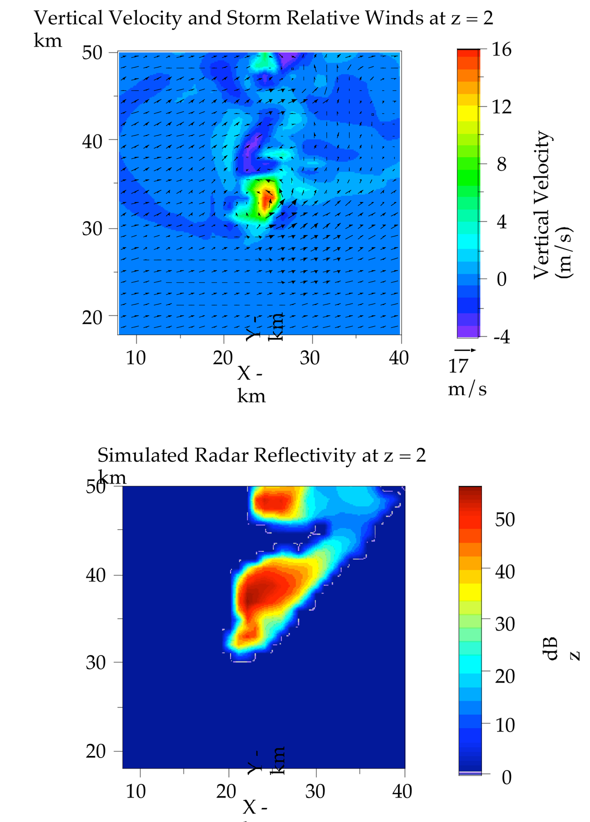

Figure 4 A horizontal plane through the simulated storm at a height of 2.1 km after 1 hour of integration. TOP) The storm's updraft is 17 m s^{-1} at this level. The diameter of the updraft is approximately 5 km. Wind speeds around the storm exceed 18 m s^{-1} and strong cyclonic shear is evident in the storm-relative wind field around the eastern and northern portion of the updraft. The areal extent of the storm's wind field at this level is about 10 km in diameter; twice the size of the updraft. BOTTOM) The simulated radar reflectivity field exhibits an elongated echo extending northeast to southwest. At low levels, a notch-like indentation exists near the southern end of the echo. The notch is co-located with the maximum inflow associated with the low-level rotation.

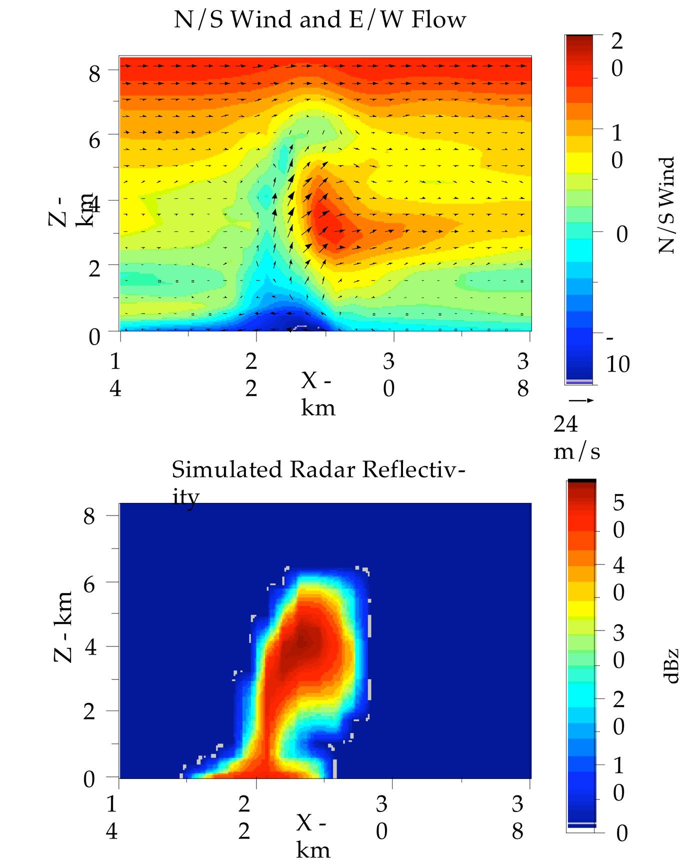

Figure 5 West-east vertical cross section through the storm's maximum updraft at 1 hour. TOP) U-w component wind vectors and color image field of the v-component (north-south) wind. The storm's maximum vertical velocity is 21 m s^{-1}. Regions of red indicate flow into the page, while regions colored blue indicate flow out of the page. The flow pattern seen, with positive v on the east side of the updraft, negative to the west, is indicative of a moderate mesocyclone circulation which extends from the surface to near the top of the storm. BOTTOM) Simulated radar reflectivity only extends upward to 6 km altitude, indicative of the shallow nature of the supercell. The weak echo region occurs at about 1.5 km aloft associated with an echo overhang.

Idealized Simulation Soundings

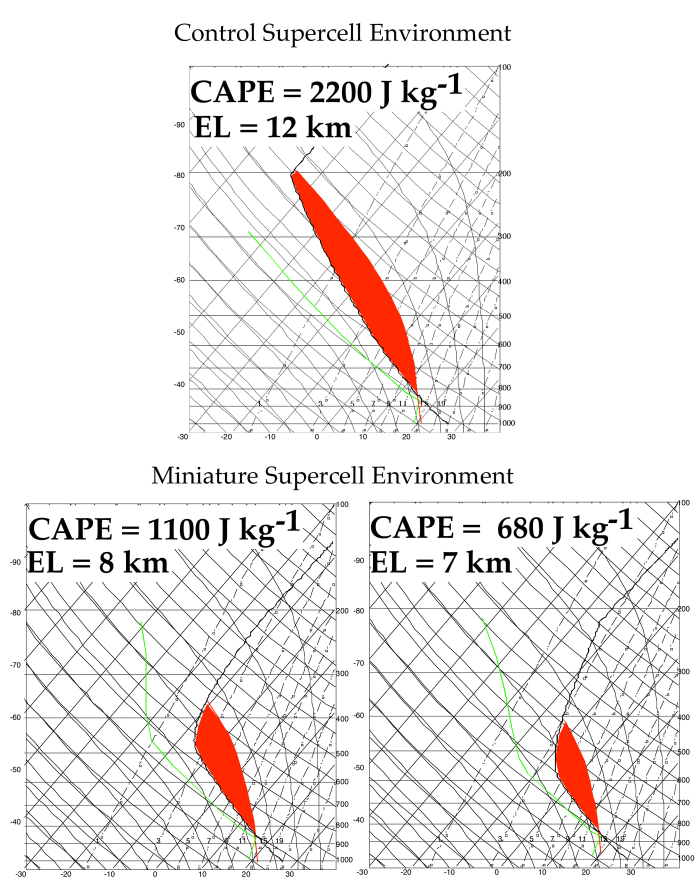

Figure 6 The environmental soundings used for the simulations. Below 600 mb, the profile of parcel buoyancy is identical. A straight-line hodograph is used for the vertical shear.

Low Level Fields at 2 Hours

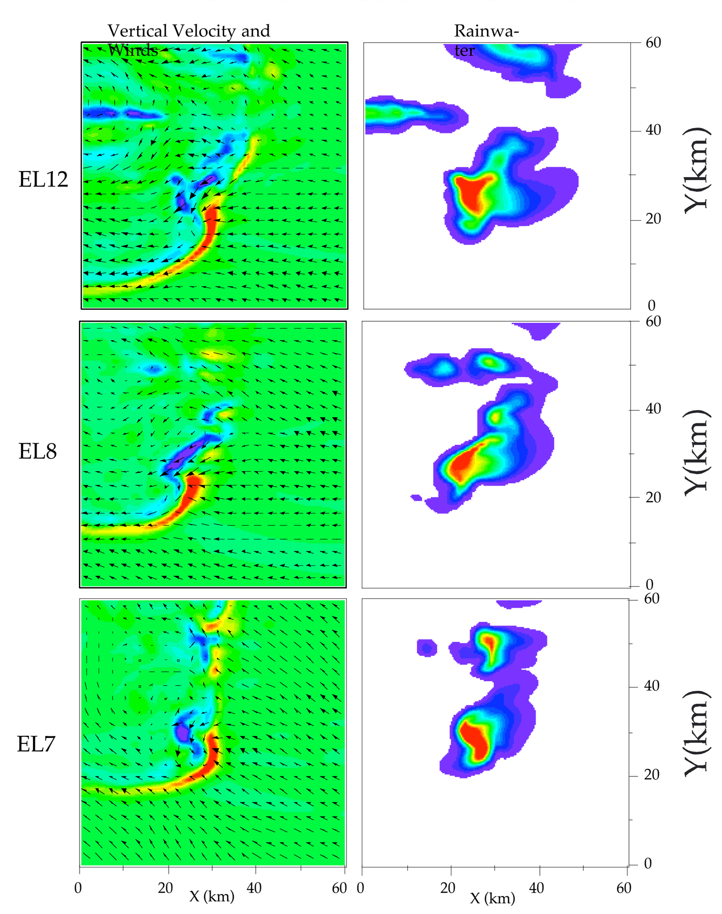

Figure 7 Horizontal slices at z = 1 km and t = 2 hours from the three simulations using the soundings shown in Figure 6. LEFT) Regions shaded red indicate updrafts at low levels, with blue shading indicating downdrafts. Storm-relative flow fields are shown as vectors. RIGHT) Storm reflectivity at low levels.

Midlevel Fields at 2 Hours

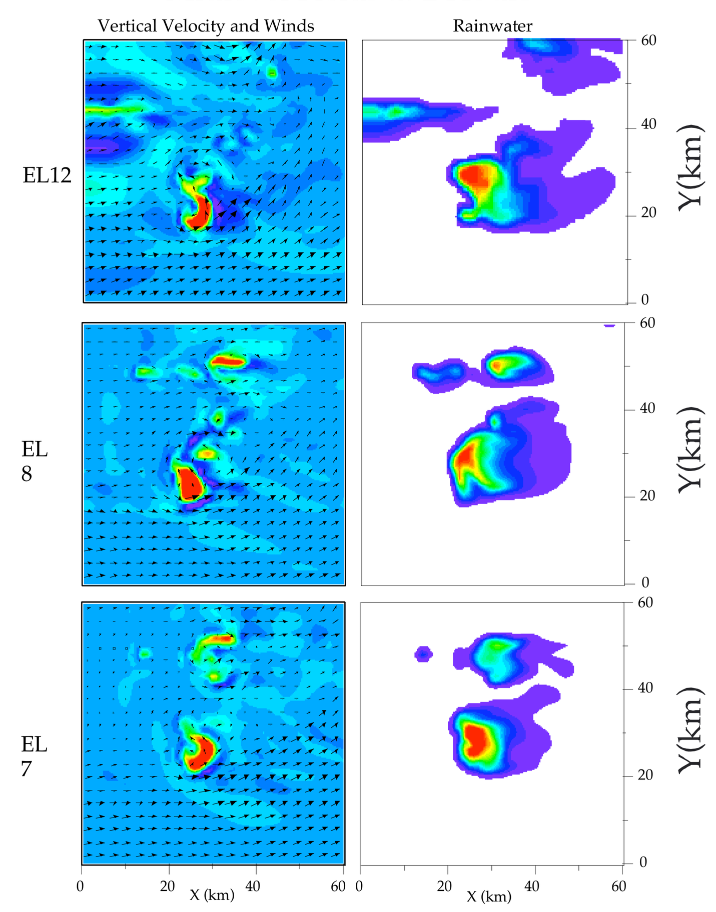

Figure 8 Horizontal slices at z = 5 km and t = 2 hours from the three simulations using the soundings shown in Figure 6. LEFT) Regions shaded red indicate updrafts and regions shaded blue indicate downdrafts at midlevels. Storm-relative flow fields are shown as vectors. RIGHT) Storm reflectivity at midlevels.

West to East Vertical Cross Section at 2 hours

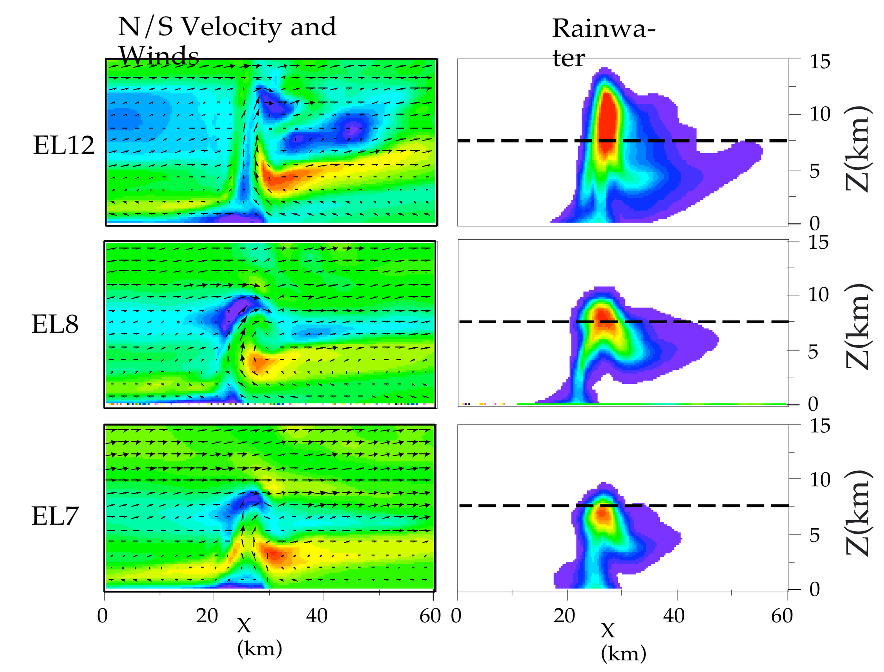

Figure 9 West to east vertical cross sections through the maximum updraft in each of the three storm simulations. LEFT) The color image field is the v-component (north-south) of the wind field. Regions of red indicate flow into the page, while blue colored regions indicate flow out of the page. The vector field superimposed is the west to east storm-relative flow in the plane of the slice. RIGHT) West to east cross vertical section of storm rainwater.

Time Averaged Vertical Distribution of Maximum Updraft for 0.006 s^{-1} and 0.008 s^{-1} cases

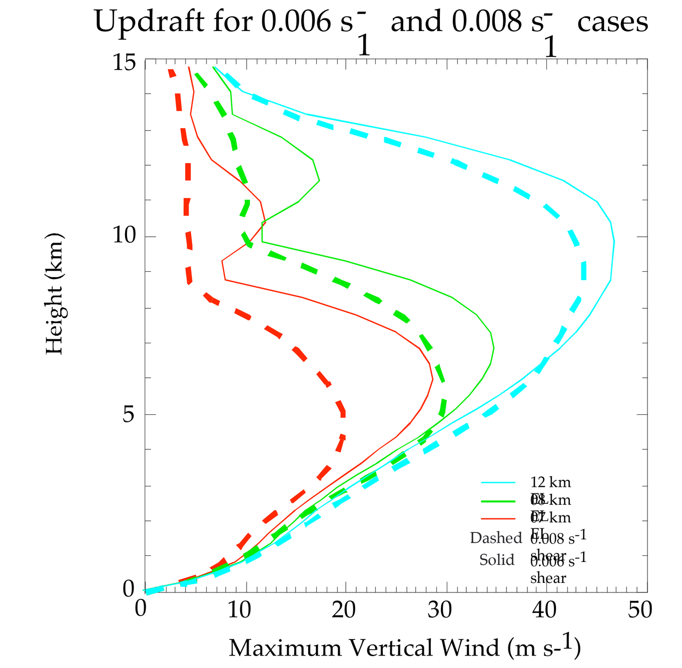

Figure 10 The time averaged vertical distribution of maximum updraft. Dashed lines represent environmental vertical shear of 0.008 s^{-1} and solid lines 0.006 s^{-1} vertical shear cases. The cases with the 0.006 s^{-1} vertical shear have stronger updrafts compared to the 0.008 s^{-1} vertical shear cases. In addition, the distribution in the lower 4 km is similar despite the maximum updraft strength depending upon CAPE.

Forcing Terms and Measured Updraft Strengths Through Maximum Updraft Core for 0.006 s^{-1} Cases

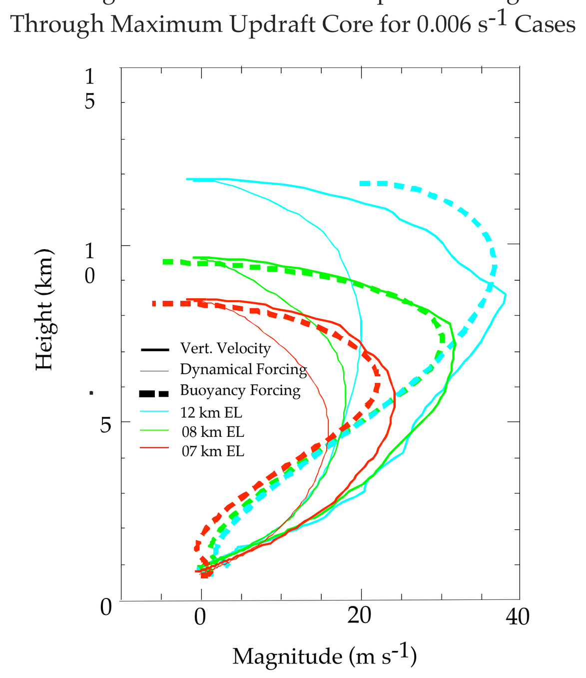

Figure 11 Forcing terms and updraft strength following a trajectory path through the maximum updraft in each storm. The thin dashed lines, the thin solid lines and the thick solid lines represent the integrated buoyant forcing, the integrated dynamical forcing and the maximum vertical velocity respectively. The dynamical forcing, associated with the vertical pressure gradient induced by storm rotation, dominates the updraft forcing below 5 km. Above 5 km, buoyant forcing governs the vertical motion. Hence, the three simulations exhibit similar features due to the predominance of dynamic forcing in the lower levels.

Evolution of the Vertical Distribution of the Maximum Vertical Vorticity

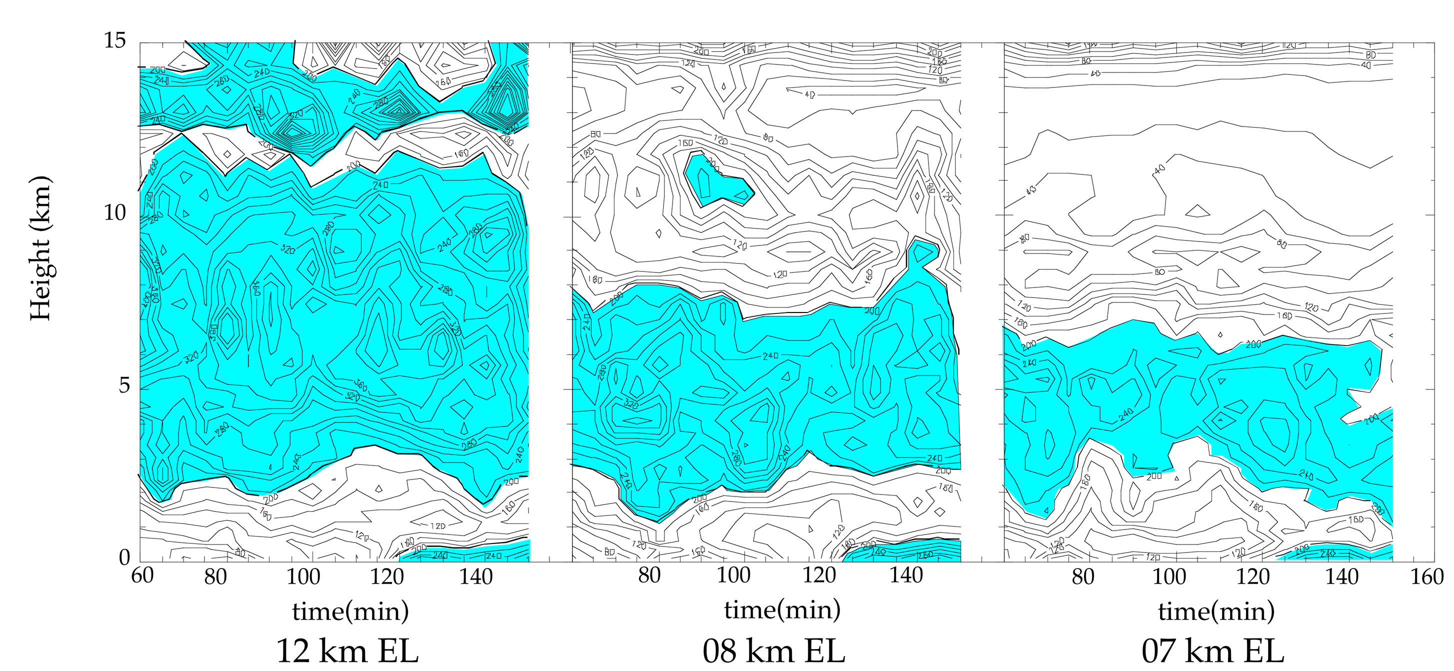

Figure 12 The time versus height evolution of the maximum vertical vorticity for the 0.006 s^{-1} vertical wind shear cases. The contour interval is 20x10 $^{-4}$ s^{-1} and the blue shading represents positive vertical vorticity magnitudes greater than 0.02 s^{-1}. (This vertical vorticity could be thought of as a 40 m s^{-1} rotational velocity across a vortex 4 km in diameter.) For each case the altitude of the midlevel mesocyclone scales linearly with the depth of the storm. In addition, all three simulations exhibit the formation of a low-level mesocyclone of similar strength around 120 minutes.

Conclusions

- The typical radar features observed in deep supercells (i.e., bounded weak echo regions, midlevel mesocyclones, hook echos, etc.), are seen in both observed and simulated miniature supercells and appear to scale both vertically and horizontally as storm size decreases.
- The simulated Shackleford County storm of 19 February 1994 has many features in common with the observed storm. In particular, both had midlevel circulations confined below ~6 km and strong low-level mesocyclones.
- In the idealized simulation study, low-shear (0.004 s^{-1}) environments produce supercells which evolve into multicells after 1 hour, moderate and high shear environments produce long lived supercells for the entire range of CAPE values.
- Similar low-level mesocyclones occurred in environments with moderate to high vertical wind shear even though total CAPE is two to three times smaller in the miniature supercell cases.
- Storm characteristics (e.g., supercell versus multicell) appeared to be determined by the shear and CAPE value in the layer between the surface and 5-6 km.
- The miniature supercells studied here are similar to those supercells found in tropical storm and hurricane environments (McCaul 1993; McCaul and Weisman 1996).

[1] *Presented at the 18th Conference on Severe Local Storms February 19-22, 1996 in San Francisco, California*

[2] *Poster created by Matt Gilmore and Steve Peckham*

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