The Role of a Squall-line and Boundary Interaction in the Development of the Long-lived 21-22 July 2003 Tornadic Supercell across Eastern New York and Western New England

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1. Introduction

A mesoscale convective vortex (MCV) moved across northern Pennsylvania (PA) into southeast New York (NY) on 21 July 2003. The MCV originated from an area of convection over eastern Iowa (IA) around 0300 UTC. The system strengthened and acquired a large comma-shaped satellite signature as it moved across the Midwest reaching central New York by 0130 UTC on 22 July 2003. A line of strong convection extending south from the vortex center crossed eastern NY, where previous convection had created an outflow boundary. Widespread severe weather ensued, including a long-lived supercell responsible for a series of tornadoes with a maximum F2 intensity (Fig. 1).

The convection developed in a highly favorable dynamic environment. Eastern NY and western New England were located in the right-rear quadrant of the 250 hPa upper level jet, which was an area of strong, concentrated divergence. A strengthening southerly 850 hPa low-level jet intensified to 50 kt as it crossed the Hudson Valley. Winds increased and veered from the surface through the mid troposphere. This created a shear profile coupled with large mixed layer convective available potential energy (MLCAPE) values favorable for severe weather, including bow echoes and supercells.

A detailed radar analysis of the evolution of the long-lived tornadic supercell will be presented. It will be shown that southeasterly (backed) flow associated with the pre-existing boundary in the Hudson Valley increased the low-level shear, which may have created a favorable environment for tornadogenesis. The radar analysis will further show that supercell dynamics were present, with a tornadic signature of varying intensity evident during the non discrete supercell lifecycle.

2. Synoptic Overview

A strong positively tilted 500 hPa longwave trough was in place over the Great Lakes region and Northeast at 1200 UTC 21 July 2003 (Fig. 2). A series of short waves were moving through the trough. One convectively induced vorticity maxmima developed into a MCV over eastern IA at about 0300 UTC 21 July 2003. This vortex developed south of a cold front which was descending south from the upper Midwest, and along and ahead of a stationary boundary over the upper Mississippi River valley and Midwest. This vortex continued to progress in the 40-50 kt mid-level flow to northeastern Indiana and northwestern Ohio (OH) by 1200 UTC. The convection continued to develop in the vicinity of a strong 250 hPa jet streak of 90-100 kt over eastern Michigan, Lake Superior and southeastern Ontario at 1200 UTC (Fig. 3a). Upstate NY and PA were forecast to be in the favorable right-rear quadrant of the upper-level jet streak, and strong upper-level divergence was forecasted (Nemeth Jr. and Farina 1994). An impressive 850 hPa wind maxima of > 40 kt was moving through southern OH at 1200 UTC (Fig 3b). The southwesterly low-level jet would be a focusing mechanism for supercell development and potential tornadogenesis in portions of PA and NY later that afternoon. The low-level jet strengthened in time to greater than 50 kt from the south/southeast and helped advect in higher dewpoints in excess of 20°C with rich equivalent potential temperature (>340 K, not shown) air in the low levels of the atmosphere.

3. Sounding and Mesoscale Analysis

The upstream sounding at Pittsburgh (KPIT) at 1200Z 21 July 2003, modified with a peak surface temperature and dewpoint of 28°C and 20°C, respectively, produced surface-based CAPE in excess of 3000 J kg^{-1} (Fig 4). The modified sounding also showed a 0-3 km storm relative helicity (SRH) value of 209 $(m/s)^2$. This was an upstream indication that the potential threat of tornadoes may be increasing with the intensifying low-level jet and increasing 0-3 km SRH values to 200-300 $(m/s)^2$. The wind profile also showed strong veering of the winds in the 0-2 km layer. The flow was highly unidirectional in the lower- to mid-troposphere, which was indicative of the potential for a convective mode of a squall line(s) with embedded bows.

Between 1600 UTC and 2100 UTC the MCV produced a squall line with line echo wave patterns (LEWPs) and some tornadic supercells over central PA. Several areas of thunderstorms crossed northern PA and southern NY well in advance of the MCV and its associated squall line. One area of thunderstorms over northwest PA at about 1300 UTC moved northeast reaching the Binghamton (BGM) area about 1700 UTC and the Albany (ALB) area near 2000 UTC (Fig. 5). The activity weakened over

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southern VT by 2130 UTC. As the storms moved east away from BGM, bowing segments developed and produced more than six reports of wind damage from the northern Catskills eastward across the Greater Capital Region.

In addition to producing severe weather, this initial convection may have played a role in the evolution of a long-lived supercell several hours later. In the wake of the thunderstorms, a large area of rain-cooled air lay across east-central NY. At ALB the temperature climbed to ~27°C (80°F) but then dropped to 20°C (68°F) just after 2000 UTC, as the thunderstorms with heavy rain and wind gusts to 36 kt passed. Meanwhile, to the south at Poughkeepsie, NY (POU), temperatures rose to 29°C (84°F) at 2000 UTC and remained close to 27°C (80°F) through 2300 UTC, with the dewpoint reaching 22°C (73°F). The wind at POU remained consistently out of the south, while at ALB a south wind at 2000 UTC shifted to the west a few minutes later and gusted to 36 kt with the arrival of thunderstorms. During the next 3 hours the wind varied in direction from east to north. The temperature and wind profiles at ALB and POU indicated the likely presence of a thunderstorm-induced outflow boundary to the south of ALB.

Visible satellite imagery presents further evidence of the existence of the boundary and helps pinpoint its location (Fig. 6). At 2215 UTC bright clouds in south-central VT are the remnants of the convection that brought severe weather in the mid-afternoon to east central NY. A band of cumulus and towering cumulus extended southwest from the convection across northwest Massachusetts (MA), the Hudson Valley and into the southern Catskills. This line of cumulus development formed along the pre-existing outflow boundary, and would later interact with the upstream MCV.

The 22/0000 UTC Albany (ALY) sounding shows how volatile the convective environment was over portions of eastern NY and western New England (Fig. 7). The ALY sounding showed a MLCAPE value in excess of 3000 J kg^{-1}, as well as a minimal mixed layer convective inhibition of -160 J kg^{-1},. The instability is elevated above 2 kft due to the earlier convection. The lifting condensation level (LCL) is low, under 3 kft. Previous research has shown environments with low LCLs are favorable for tornadic development, especially in the presence of pre-existing outflow boundaries (Markowski et al., 1998). The 0-6 km deep shear was 57 kt, which indicated the potential for deep organized convection. The 0-1 km and 0-3 km SRH values of 342 and 430 $(m/s)^2$ were a red flag for severe convection with a strong possibility of tornadoes. These extremely high helicity values were generated by the substantial low-level veering in the surface to 5 kft layer. The veering wind profile at ALY had increased with time up to 22/0000 UTC. At 21/1200 UTC, the 925 hPa winds at ALY were southwest at 20 kt, and backed to southeast at 25 kt by 22/0000 UTC. By 22/0000 UTC, a south/southeasterly 850 hPa jet of 50 kt was in place over the Hudson River Valley.

4. Storm Scale Radar Analysis

The MCV began to lose some of its comma-shaped radar signature and weaken as it encountered the strong low-level shear across eastern New York. KENX radar images show that by 2336 UTC convection with reflectivity values greater than 50 dBz had developed along the old outflow boundary (not shown) as the squall line associated with the weakened MCV approached from the west and intersected the boundary in the eastern Catskills. During the next 15-20 minutes, convection along the outflow boundary solidified (Fig. 8), but during the subsequent 30 to 40 minutes it gradually became absorbed into the squall line (not shown).

Earlier, a mesocyclone with a rotational velocity (v_r) of 31 kt was observed on the KENX radar 0.5° scan at 2316 UTC in Sullivan County, NY near the point where the outflow boundary initially intersected the squall line, and an F1 tornado was reported (not shown). The mesocyclone weakened temporarily and no new tornadoes were reported for the next 56 minutes. However, as the storm moved through northern Ulster County it again intensified (Fig. 8). The merger of the old outflow boundary and the squall line can be viewed to the south of the KENX radar at 2352 UTC (Fig. 8). By this time, the observed v_r increased to 45 kt at both 0.5° (4400 ft MSL) and 1.5° (7200 ft MSL). The KENX VAD Wind Profile indicated a 20 kt wind from the southeast at 2 kft, 35 kt out of the south at 3 kft, and 40 kts from the south/southwest at 4 kft. This provides further evidence that backed (southeasterly) low-level flow helped create a strong veering profile in the lowest 5 kft prior to tornadogenesis.

At 0014 UTC 22 July an F1 tornado was observed in southern Greene County, near the border of Ulster County. At 0019 UTC, a distinct mesocyclone with a radar detected tornadic vortex signature (TVS) was present (Fig. 9). The tornado intensified with F2 damage reported at 0023 UTC in the hamlet of Kiskatom in the town of Catskill, east of the initial touchdown. During the next hour, the portion of the squall line south of the mesocyclone accelerated relative to the northern portion of the line and a LEWP developed. At the bend in the LEWP a distinct supercell persisted for several hours and produced a series of tornadoes from the mid-Hudson Valley into southern VT (Fig. 1).

As the supercell moved into south central VT it evolved into a northern bookend vortex with a significant bowing segment south of it that produced the Cavendish, VT tornado (Atkins and Taber, 2004).

Figure 10a) shows the gate-to-gate time series analysis of the strong mesocyclonic couplet from 2331 UTC to 0156 UTC at the 0.5° elevation angle from Volume Coverage Pattern-11. The mesoscyclone with the radar detected TVS (not shown on figure) at 0040 UTC produced a v_r of about 45 kts and a v_r shear value of 0.052 s^{-1}. The supercell with the strong mesocyclone was at the apex of its lifecycle at this point. Local office research studies have shown these values to be capable of producing F2 or greater tornadoes in the Northeast. Figure 10b) shows a hook echo over northern Columbia County with the impressive radar detected TVS from the tornadic mesocyclone.

5. Discussion and Summary

LaPenta et al. (2005), and Goodman and Knupp (1993) documented cases where tornadoes formed in association with squall line-supercell mergers. In the 21-22 July case, convection set up an outflow boundary ahead of the line of storms. Subsequent convection, which developed on this boundary, was absorbed into the line of storms which was associated with an MCV. A tornadic supercell developed near the point of intersection of the squall line and the downstream convection on the boundary. Other studies have also shown the importance of boundary interactions in tornado formation, although in these studies squall line-supercell interactions were not present in all cases. In a study of 86 tornadoes in the northeastern United States, LaPenta et al. (2000) indicated radar detectable boundaries were present in about a fifth of the cases. These studies point to the complexities involved in the tornado formation process, and show that boundaries can be an important source of environmental heterogeneity.

The July 21-22, 2003 case involved a squall line moving into eastern NY and Hudson River Valley intersecting with an old outflow boundary from convection less than 5 hours earlier. The result was a long-lived supercell on a squall line producing a long broken-track tornado (Fig. 1) southeast of the KENX radar site. The favorable environment for supercellular development was evidenced by MLCAPE in excess of 3000 J kg^{-1} and low-level SRH values in excess of 400 $(m/s)^2$. We speculate that increased low-level shear which may have aided in tornadogenesis was created as surface flow backed to southeasterly in the Hudson River Valley, resulting in strong veering below 5 kft.

6. Acknowledgements

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7. References

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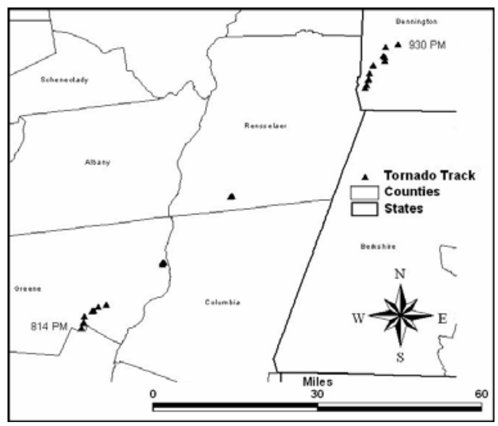

Fig 1: The tornado track of the long-lived supercell along the line.

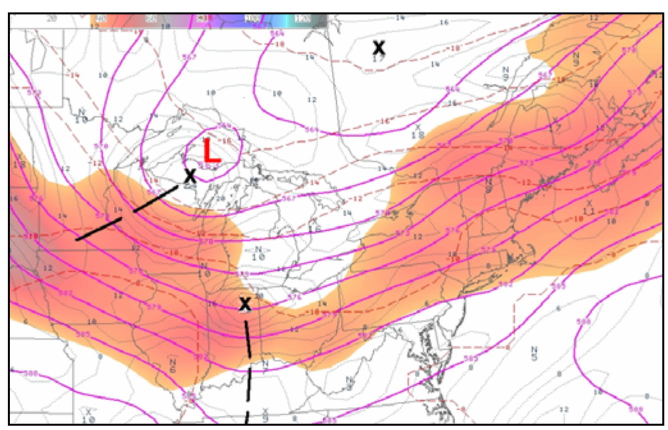

Fig. 2: Eta 500 hPa analysis of height (purple solid, dam), temperature (dashed, °C), absolute vorticity (dotted, x 10^{-5} s^{-1}), isotachs (shaded > 35 kt) and short waves (black) at 1200 UTC 21 July 2003.

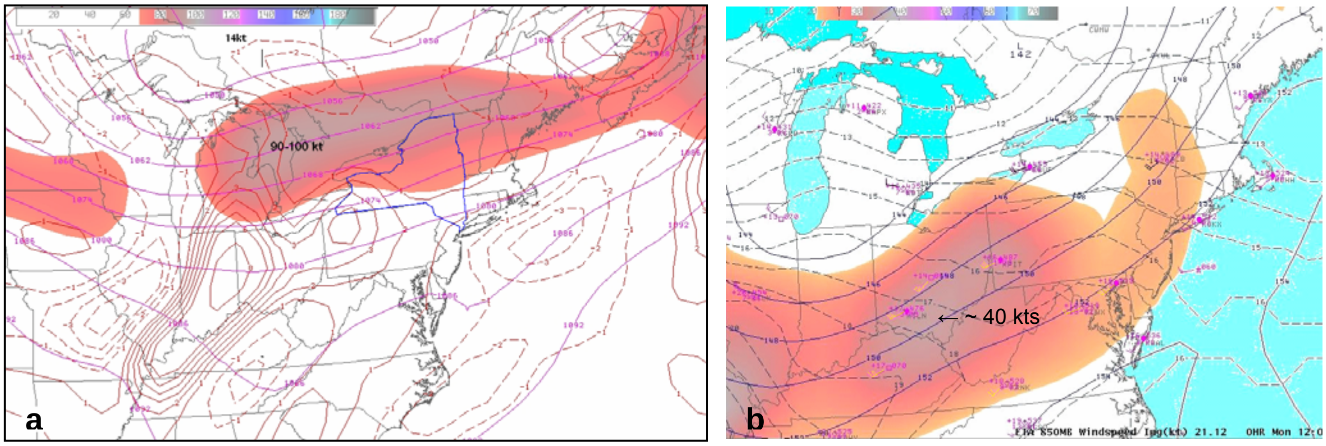

Fig. 3: Eta analysis at 1200 UTC 21 July 2003 of a) 250 hPa analysis of height (purple, solid), divergence (red, solid, $(x10^{-5}\ s^{-1})$), and isotachs (shaded greater than 70 kt), and b) 850 hPa analysis of height (dam, solid), isotachs (shaded >20 kt) and temperature (dashed, ˚C).

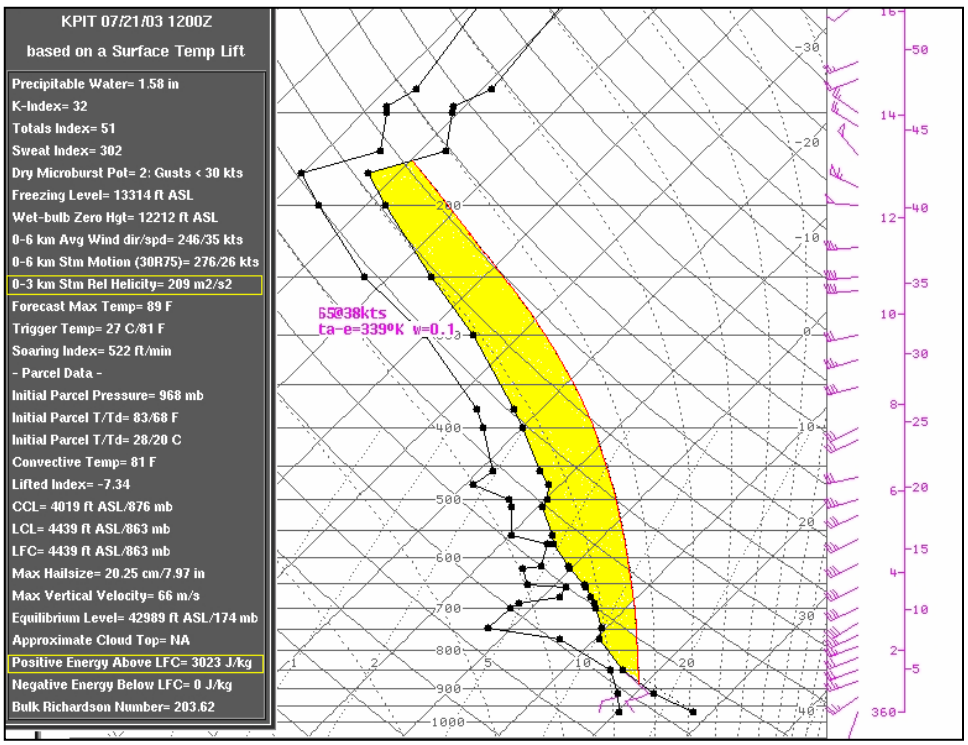

Fig. 4: Pittsburgh modified 1200 UTC 21 July 2003 sounding in AWIPS for peak temperature (28°C) and dewpoint (20°C) before the severe weather. Winds are in kt.

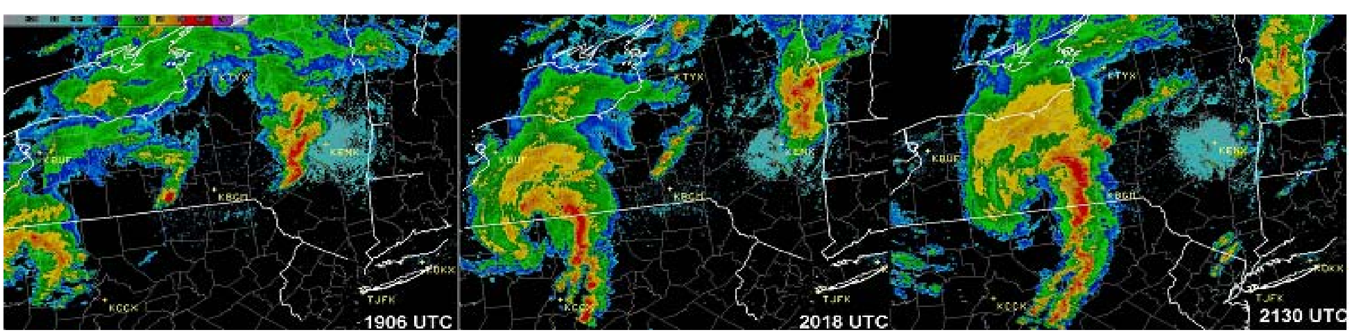

Fig. 5: Northeast regional mosaic radar reflectivity (dBz) images at 1906, 2018 and 2130 UTC.

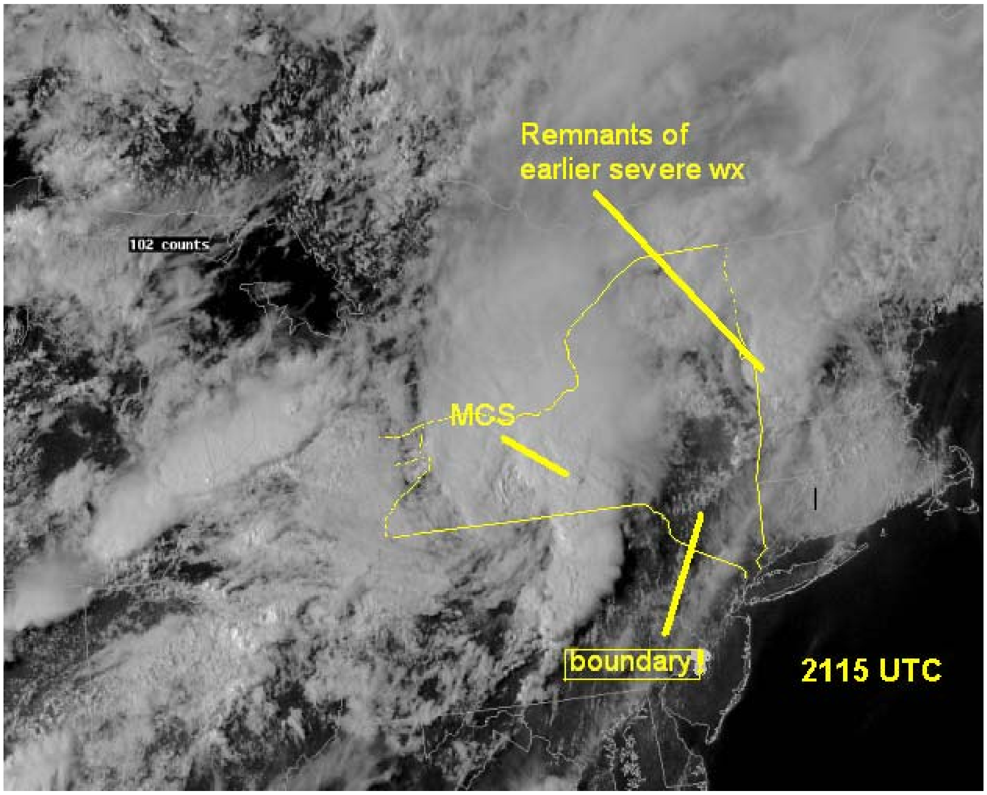

Fig. 6: 2115 UTC 21 July 2003 Northeast visible satellite image.

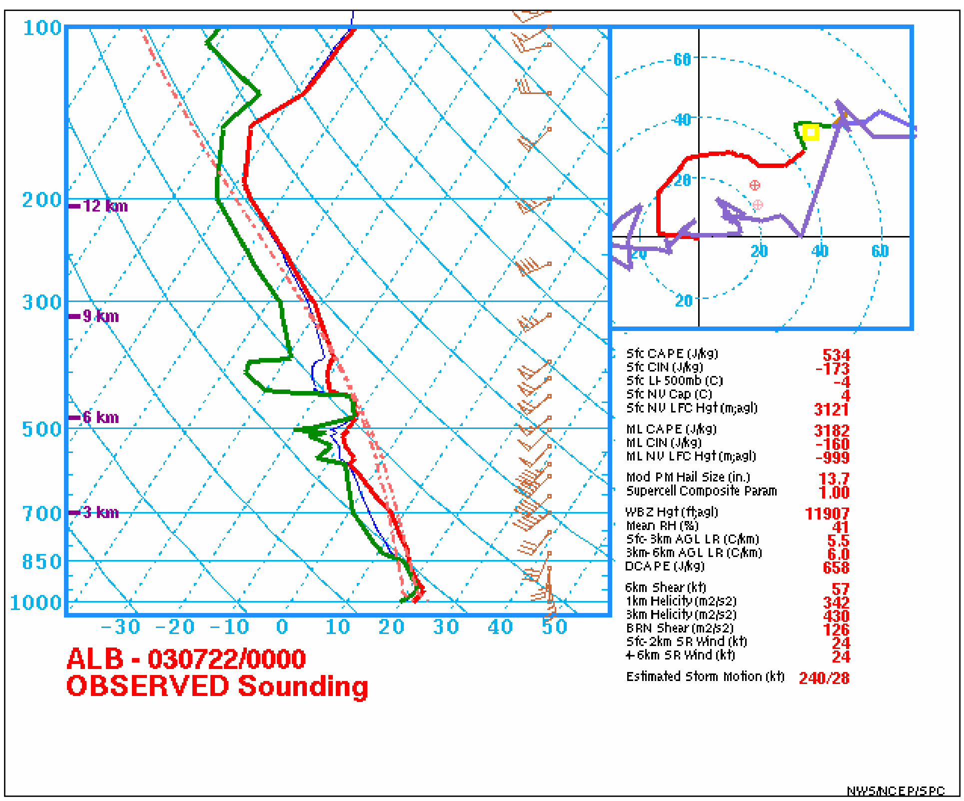

Fig. 7: Albany 0000 UTC 22 July 2003 sounding (http://www.spc.noaa.gov).

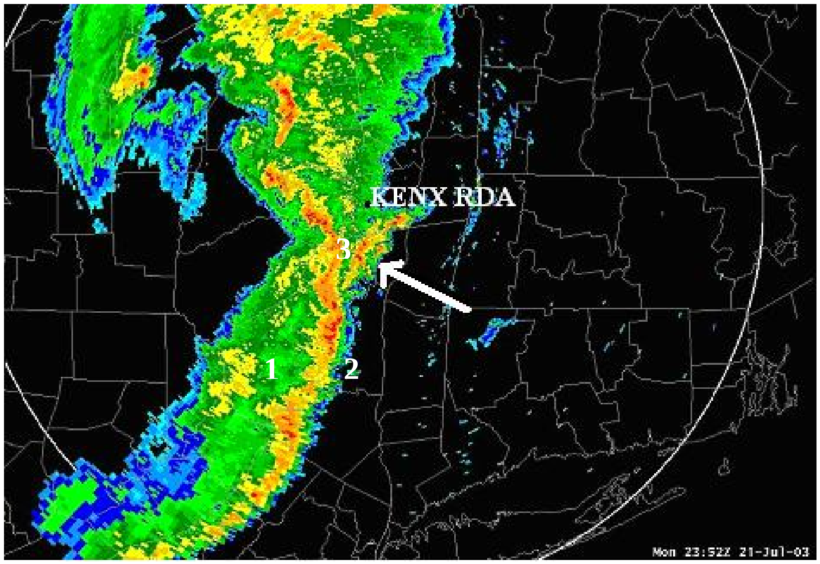

Fig. 8: KENX 2352Z 0.5º base reflectivity (dBz). The squall line is colliding with the boundary south of the radar in southern Greene County. 1 is Sullivan County, 2 is Ulster County and 3 is Greene County.

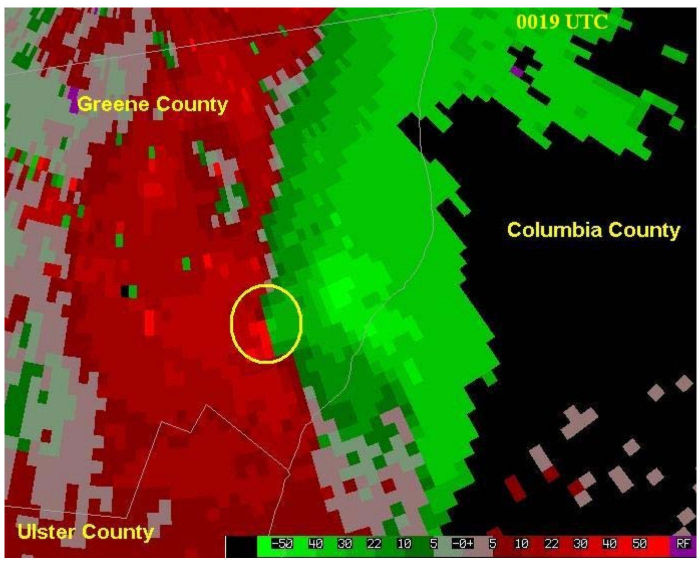

Fig. 9: KENX 0.5º SRM Albany 0019 UTC 22 July 22 over southeastern Greene County.

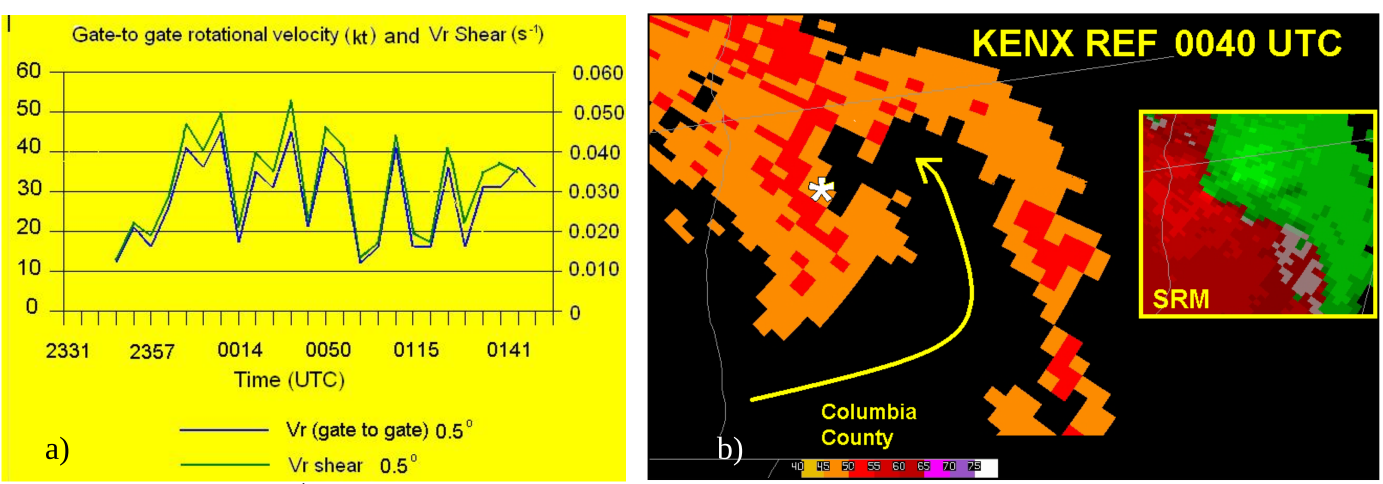

Fig. 10: a) Vr Shear (s^{-1}) and Vr (kts) from KENX radar focusing on supercell on the line. The x-axis time step is 5 minutes in volume coverage pattern-11. b) 0040 UTC 22 July 2003 0.5 º base reflectivity and SRM KENX radar images of the supercell. The radar is west-northwest of the storm.