A Comparison Study of VIL VS Rotational Velocity associated with Tornadic Thunderstorms

Ronald A. Murphy Kevin J. Pence James A. Westland Robert E. Kilduff

NOAA/National Weather Service Forecast Office
465 Weathervane Road
Alabaster, Alabama 35007

1. Introduction

Peters and Kilduff (1993) studied a tornadic storm that moved across southern Cherokee County, Alabama. Their study compared values obtained from the Vertical Integrated Liquid (VIL) product, to rotational velocities computed from the Base Velocity (V) product during the life of the storm. In their paper, it was suggested that during the collapse phase of the storm, VIL values decreased, and at the same time the rotational velocities values increased. This was a possible indication of the onset of severe weather. This fluctuation occurred between the times of 0038 and 0049 UTC (Fig. 1) along with several other deviations. This study is a continuation of their work, but analyzes the tornado outbreak on Palm Sunday 27 March 1994.

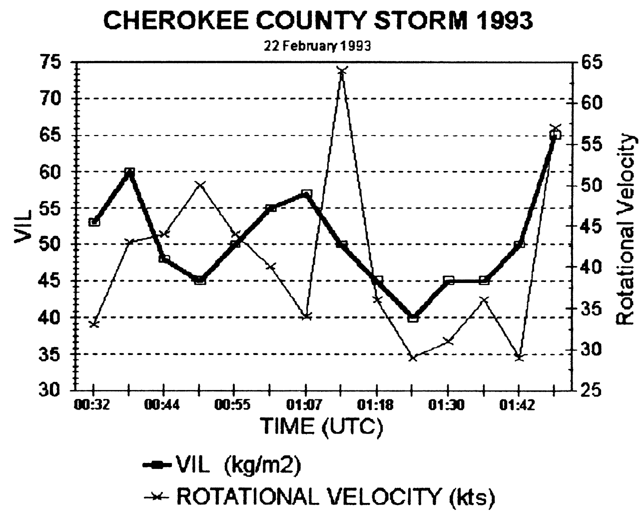

Fig. 1. Comparison of VIL and V_{rot} with time for the Cherokee County storm of 1993. VIL shown as a dark thick line and rotational velocity as a thin line.

2. Methodology

This study used archived data from the DOD East Alabama WSR-88D (KMXX) site located in Northwestern Macon County near Carrville, Alabama. Archived data used from the KMXX WSR-88D were from the Palm Sunday Tornado Outbreak on 27 March 1994. The radar was in VCP 21 during the Palm Sunday event and for the storm described in the Peters and Kilduff study.

Maximum values of VIL (kg/m²) were obtained from the VIL product, and storm relative velocities from the SRM product. Mid-range values of the inbound (V_{in}) and outbound (V_{out}) velocities were taken (Table 1. Keighton 1994) and rotational velocities were computed using $V_{rot}=(|V_{in}| + |V_{out}|)/2$. Unfortunately, the archive only contained SRM data at the 0.5, 1.5 and 2.5 degree elevations.

Table 1. Storm Relative Velocity

Display	Mid-Range
-50	-55
-40	-45
-30	-35
-22	-26
-10	-16
-5	-8
-1	-3
0	3
5	8
10	16
22	26
30	35
40	45
50	55

Table 1. Mid-range values used to obtain storm relative velocity (Keighton 1994).

An average V_{rot} through the storm was computed to see how these values compared to the 0.5 degree elevation scan used in the previous study. There was not a significant difference between the 0.5 degree elevation V_{rot} and averaged V_{rot}. Although this study mainly looks at 0.5 degree Vrot, 1.5 degree Vrot was included in the following figures due to gaps in the 0.5 degree V_{rot} because of range folding.

3. The Environment

Strong southwesterly flow dominated the upper-level wind pattern over the southeastern states on the morning of 27 March 1994. At 1200 UTC, a southerly low-level (850 mb) speed maximum of greater than 25 m/s (≈50 kt) was exiting the region, while a second southerly speed maximum of greater than 25 m/s (≈50 kt) was moving over the Louisiana coastline. 500-mb wind speeds of 30 to 40 m/s (≈60 to 80 kt) were widespread from Texas to Georgia in the strong southwesterly flow aloft. A jet streak of 70 m/s (≈140 kt) was noted over Missouri and Illinois at 300 and 200 mb. At the surface, a slow moving cold front was positioned over the northwestern corner of Alabama, while a trough extended eastward across northern Alabama and northern Georgia. Early morning surface dew points were in the upper 60s and lower 70s (F) over southern Alabama. Quasi-geostrophic forcing was relatively weak over the southeastern states. Q vectors for both 850-500 mb and 500-300 mb layers at 1200 UTC indicated very little vertical forcing on the synoptic scale.

In spite of the weak quasi-geostrophic forcing, warm and moist low-level air was being lifted along the surface boundaries. The SHARP Workstation (Hart and Korotky 1991) presentation of the unmodified 1200 UTC Centreville, Alabama (CKL) sounding (Fig. 2a and 2c) indicated an observed CAPE (convective available potential energy) of 1,193 J/Kg, with 0 J/Kg of CIN (convective inhibition). The CAPE increased to 2,665 J/Kg by 1800 UTC (Fig. 2b and 2d). The mean wind in the lowest 6 km (at CKL) increased from 23 m/s (≈43 kt) at 1200 UTC to 28 m/s (≈54 kt) at 1800 UTC out of the southwest. This wind speed increase was associated with increasing temperature gradients (frontogenesis) throughout the troposphere. The hodographs indicated wind shears of greater than 50 kt in the lowest 6 km at both 1200 and 1800 UTC. The SHARP Workstation's computed storm motion was relatively close to the actual storm motion at 1800 UTC. This storm motion produced a storm-relative helicity (0-3 km) of 510 m^2/s^2 , which resulted in an energy/helicity index (Hart and Korotky, 1991) of an incredible 8.49. Hart and Korotky (1991) suggested that 1.0 is indicative of a significant tornado potential, while Davies (1993) suggested that 2.0 or 2.5 may be a better indicator of a significant tornado event. It was in this moderately buoyant and highly sheared environment that several supercells developed over northern Alabama on Palm Sunday 1994.

4. Findings

Out of the several storms studied, two storms were used and compared with the findings of 22 February 1993 Cherokee County, Alabama storm. These two storms exhibited the same dramatic decrease in VIL values with a corresponding increase in V_{rot}, as did the 22 February 1993 Cherokee County storm.

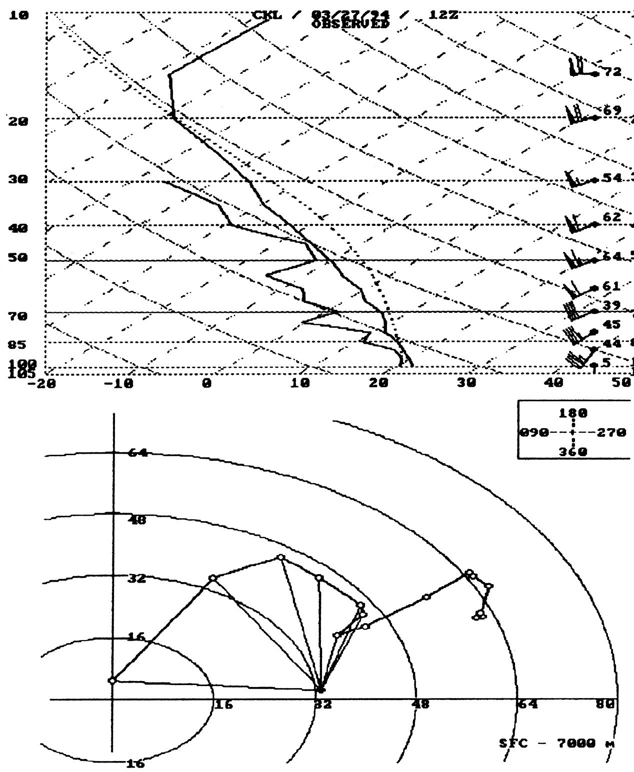

Fig. 2a. Centreville, AL (CKL) sounding and hodograph at 1200 UTC on 27 March 1994.

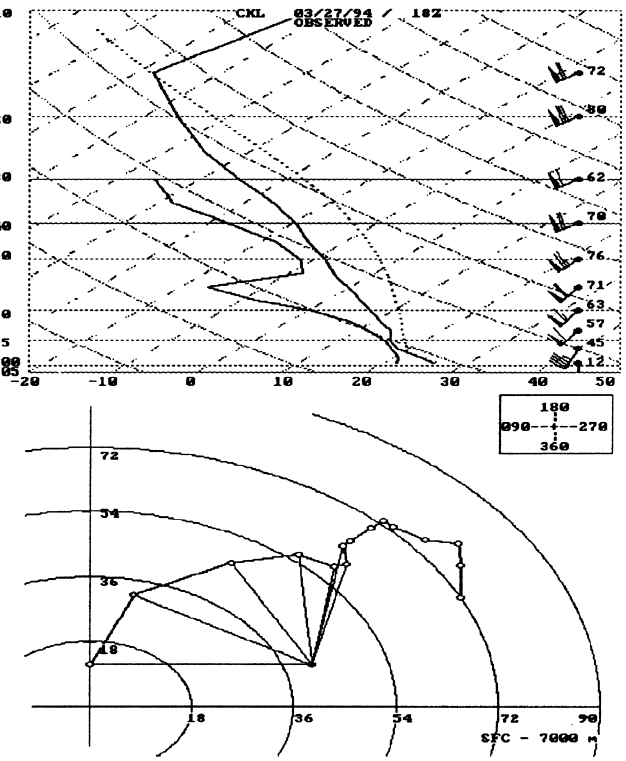

Fig. 2b. Centreville, AL (CKL) sounding and hodograph at 1800 UTC on 27 March 1994.

OBSERVED SOUNDING PARAMETERS
for Centreville, AL March 27, 1994 at 1200 UTC

CONVECTIVE POTENTIAL

K-Index............ 31	B+............. 1193 J/Kg
Precip Water....... 1.61 in.	B-............. 0 J/Kg
Showalter Index.... 1	Max UVV........ 49 m/s
LI................. -4	Cap Strength... 0.2 °C
LPL..(PMAX)........1919 ft/ 925 mb	Total Totals... 46
Tropopause......... 45000 ft.	Sweat Index.... 353
Equilibrium Level.. 40100 ft.	700-500mb LR... 6.2 °C/km
Max Parcel Level... 50300 ft.	
Wet-Bulb Zero...... 11500 ft.	TEI(800- 750). 9.9 °C

WIND / STORM TYPE

Mean Wind (0-6Km).. 235/ 43 kts	SR Helicity (0-3Km).. 435 (M/S)²
Storm Motion....... 265/ 33 kts	Pos Shear (0-2Km).. 11 (10-3 S-1)
	SR Dir Shr (0-3km).. 101°
BRN................ 11	
BRN Shear.......... 111 (M/S)²	Energy/Helicity Index...... 3.26

Fig. 2c. Observed sounding parameters for Centreville, AL 1200 UTC on 27 March 1994.

OBSERVED SOUNDING PARAMETERS	
for Centreville, AL March 27, 1994 at 1800 UTC	
CONVECTIVE POTENTIAL	
K-Index........... 33	B+............. 2665 J/Kg
Precip Water....... 1.78 in.	B-............. 0 J/Kg
Showalter Index.... -3	Max UVV........ 73 m/s
LI................. -6	Cap Strength... 0.0 °C
LPL..(PMAX)........115 ft/ 984 mb	Total Totals... 49
Tropopause......... 45400 ft.	Sweat Index.... 423
Equilibrium Level.. 45000 ft.	700-500mb LR... 6.1 °C/km
Max Parcel Level... -999 ft.	
Wet-Bulb Zero...... 11600 ft.	TEI(988- 600). 28.0 °C
WIND / STORM TYPE	
Mean Wind (0-6Km).. 223/ 54 kts	SR Helicity (0-3Km).. 510 (M/S)^2
Storm Motion....... 253/ 41 kts	Pos Shear (0-2Km).. 13 (10-3 S-1)
	SR Dir Shr (0-3km).. 99°
BRN................ 14	
BRN Shear.......... 194 (M/S)^2	Energy/Helicity Index...... 8.49

Fig. 2d. Observed sounding parameters for Centreville, AL 1800 UTC on 27 March 1994.

The first storm, hereafter called the Cherokee Storm 94, started displaying severe thunderstorm characteristics around 1622 UTC over eastern Jefferson County. The storm at this time had a tight reflectivity gradient on the inflow side of the storm, a significant overhang and weak rotation. The storm moved east northeast at an average speed of 23 m/s (≈45 kt) across St. Clair, Calhoun, and southern Cherokee Counties (figure 3). From 1622 to 1755 UTC the 0.5 degree center beam height ranged from about 8500 to 12400 feet, while at 1.5 degree it ranged 16200 to 22600 feet. During this same time span, the storm's distance from the RDA site ranged from 75 to 95 nmi.

Comparing the observed VIL and computed V_{rot} over time, figure 4 shows that between 1634 and 1645 UTC the VIL value dropped from 55 kg/m^2 to 35 kg/m^2. V_{rot}, during the same time span, was rising from 20 to 28 m/s (≈41 to 55 kt). A corresponding rise occurred at the 1.5 degree elevation. During this time, the storm was about 75 nmi from the radar site.

Included in figure 4 is a time line showing the approximate time of the tornado associated with this storm. At approximately the start of the tornado, 1655 UTC, the VIL was at its lowest value and V_{rot} had peaked. This storm produced an F4 tornado as it traversed across east-central

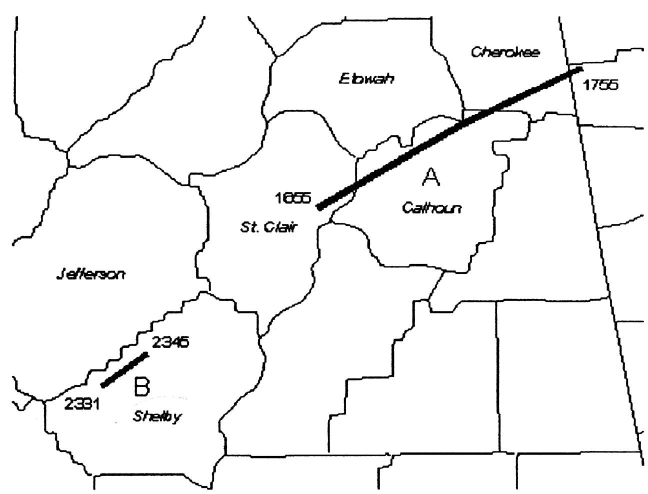

Fig. 3. The thick dark lines show the approximate path of the tornadoes. The tornado associated with the Cherokee County Storm 94 is marked by an A and the Shelby County Storm with a B.

Alabama. This was the tornado that struck the Goshen United Methodist Church, at approximately 1739 UTC, in the extreme southern part of Cherokee County, killing 20 and injuring 92 people.

The second storm, which showed a similar VIL/V_{rot} correlation, was a storm that moved across north Shelby County, track shown on Fig. 3, about six hours later. This storm slowly developed as it moved east northeast across central Alabama during the late afternoon hours. From 2250 to 2359 UTC the storm ranged from 70 to 88 nmi from the RDA site. At these ranges the 0.5 degree elevation the center beam height ranged from 7680 to 12700 feet, and at 1.5 degree elevation from 15000 to 20300 feet.

As with the Cherokee Storm 94, this storm showed the same deviation in the VIL and V_{rot}. Shown in Fig. 5, the storm reached its highest VIL at approximately 2313 UTC of 72 kg/m^2 before dropping off sharply. The VIL decreased to 47 kg/m^2 in about a 23 minute time span. As the VIL bottomed out, V_{rot} continued to climb reaching a peak of 23 m/s (≈45 kt) close to the same time. The storm's distance at 2313 UTC was 83 nmi away from the RDA site and 70 nmi at 2336 UTC. Once again range folding was a problem and the 1.5 degree elevation V_{rot} has been included on the Fig. 5. At 1.5 degree elevation, there was a rapid increase in V_{rot} during the time of the sharp fall in VIL values during the time of the tornado.

A time line has also been added to figure 5 to show the approximate period of the tornado associated with this storm. Similar to the Cherokee Storm 94, the tornado started close to the time of minimum VIL and maximum V_{rot}. An F2 tornado was produced by this storm which caused damage to homes and businesses in the Pelham and Indian Springs

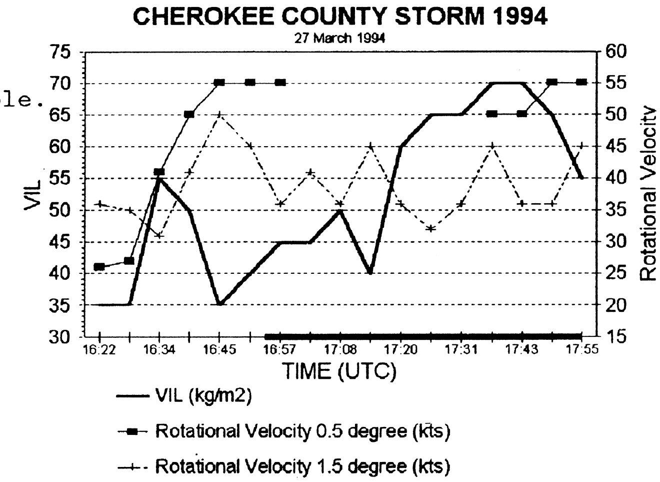

Fig. 4. VIL shown as a dark thick line. The thin line with black squares is the 0.5 degree V_{rot}, values from 1702 to 1731 UTC were missing due to range folding. The thin dashed line is the 1.5 degree V_{rot}. A dark thick line along the x-axis shows the duration of the tornado.

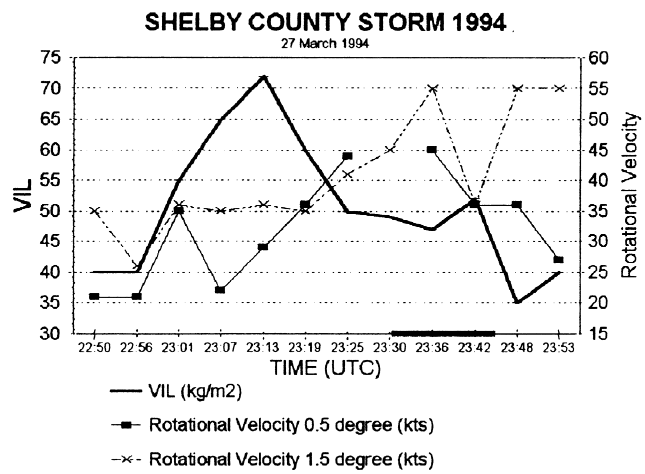

Fig. 5. VIL shown as a dark thick line. The thin line with black squares is the 0.5 degree V_{rot}, value 2330 UTC was missing due to range folding. The thin dashed line is the 1.5 degree V_{rot}. A dark thick line along the x-axis shows the duration of the tornado.

areas of north Shelby County.

In summary, both supercells displayed an abrupt decrease in VIL near or at the time of a significant rise in the V_{rot}. This is likely related to the collapse phase of the storms. Similar to a radar echo top collapse, during this collapse phase of the supercell, there is an increase in the storm's downdrafts with a corresponding decrease in the updraft. This suggests that the strongest straight-line winds and tornadic activity often occurs during the collapse phase (Lemon and Doswell 1979). As shown in figures 4 and 5, the highest V_{rot} and the tornado did not occur until the VIL values dropped off sharply. This is consistent with the collapse phase of the supercells.

Since the radar was in VCP 21 during the Palm Sunday event, there were concerns about the accuracy of the VIL product. A scan strategy study by Mahoney and Schaar 1993 showed a degradation of the VIL product in VCP 21 compared to VCP 11. In VCP 21 their computer simulations showed that VIL values are overestimated at distances greater than 50 nmi. In these two cases the storms the deviation in VIL and V_{rot} occurred at about were 70 to 80 nmi from the RDA site. However, at the time of the correlation, VIL values dramatically decrease near the onset of the tornado which may show that VIL values were reliable even at this distance from the RDA.

Two other storms were studied (not shown) and these storms did produce tornadoes as they traveled across parts of Alabama. However, neither event exhibited a well-defined deviation between VIL and V_{rot}. These events showed that a tornado will not always be preceded by these opposing trends in VIL and low-level Vrot.

5. Conclusion

The WSR-88D is obviously a great help in detecting the tornadic phase of supercells with the Doppler radial velocity capability. The combination of decreasing VILs accompanying increasing rotational velocities continues to be a very promising clue in detecting the state at which a supercell produces its first tornado. Further research into this relationship is required related to the limited amount of cases and some inconsistencies, possibly due to the VCP and distance from the RDA site.

Finally, the authors caution that the radar user should not rely on the rotational velocities shown at the 0.5 elevation slice to paint an overall picture of a storm's rotation. Although there was no significant difference between the 0.5 V_{rot} and the average V_{rot} in these cases, this was due to the storms distance away from the RDA, 70 to 95 nmi. At this distance the lowest elevation slice was high enough to detect the mesocyclone. The user should investigate several elevations to determine the depth and intensity of rotation in a storm, as well as trends throughout the depth of the storm.

Acknowledgments

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