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P1.28 An Updated Version of the V-R Shear Technique for Issuing Tornado Warnings Using 8 bit High Resolution Radar Data

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ABSTRACT

One of the original tornado warning strategies utilized after the installation of the Weather Surveillance Radar-1988 Doppler (WSR-88D) network was the V-R shear relationship. A local COMET cooperative study (LaPenta et al. 2000) found that maximum gate-to-gate shear below 3 km was useful in identifying tornadic storms. A linear relationship was established between the gate-to-gate shear and the rotational velocity of the mesocyclone. Using this concept, nomograms were developed for operational use as local tornado warning guidance. However, this relationship was very sensitive to range from the radar and was limited due to the resolution of the original 4 bit radar products. The warning meteorologist had to normalize the distance of the potentially tornadic velocity couplet used for calculating the shear value, depending on the range from the radar of the storm in question. This necessary manual adjustment could reduce valuable lead time for tornado warnings.

As a result, the goal of this Collaborative Science Technology and Applied Research (CSTAR) project was to update the nomogram of the original V-R shear study by examining tornadoes across the Northeast with the higher resolution 8 bit base radar data implemented in 2003. In addition, the study used the GR2Analyst software to view the values of normalized rotation (NROT) for several radar scans prior to the touchdown time of the tornado, which could potentially add value as a tornado warning indicator. The results, including examples from two recent tornado events, show similar conclusions as the original COMET study. Nomograms using the updated values can now be used operationally with 8 bit, high resolution radar data, which ultimately may allow for more timely warnings and improved protection of life and property.

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1. Introduction

Although tornados aren't a frequent occurrence in the Northeastern United States, they do occasionally occur in the region. In order to examine how to better predict these events a tornado climatology was completed for the Northeastern United States by undergrad atmospheric science students in the National Weather Service (NWS)-UAlbany Internship program. The climatology examined where tornadoes occur, the strength of the tornadoes on the Enhanced Fujita Scale, and the frequency of occurrence at both time of year and day.

The deployment of the Weather Surveillance Radar-1988 Doppler (WSR-88D) network in the mid-1990s allowed for huge improvement in the detection and warning of tornadoes (Simmons and Sutter 2005). One of the original warning strategies developed using this new technology was the V-R Shear relationship. A COMET study, in collaboration with the University at Albany and NWS at Albany, examined 86 tornadic cases from the Northeastern United States. The study defined the Northeastern United States as all of New England, New York (NY), New Jersey, as well as central and eastern Pennsylvania. The study found that maximum observed gate to gate shear below 3 km to be useful in identifying tornadic storms (LaPenta et al. 2000). Shear in units s^{-1} is defined by the equation:

$$S = V_r / (D * 1800)$$

In this equation, V_r is the rotational velocity in units of knots (kts) calculated across adjacent pixels and D is the distance in n mi over which the shear calculation is made (LaPenta et al. 2000).

While S accounts for the low-level rotation, nearly all tornadic supercell storms also contain a signal within the mid-level mesocyclone (Brooks et al. 1994). The previous study by LaPenta et al. considered the strength of the mid-level mesocyclone by calculating the maximum velocity differential (V_m) across the entire thunderstorm. Large values of S and V_m were highly correlated to tornado occurrence, while small values of S and V_m did not show a strong signal between tornadic and non-tornadic storms (LaPenta et al. 2000). Figure 1 shows a nomogram that was developed for operational use for storm interrogation that compares the strength of S and V_m.

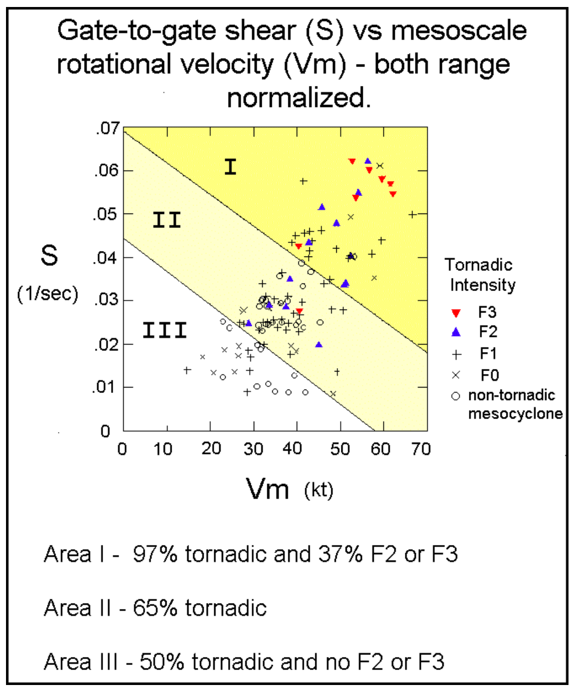

Figure 1: Nomogram created for operational use by LaPenta et al. (2000) showing a comparison of shear values (S) with mesocyclone rotation velocity (V_m).

The original Lapenta et al. (2000) study used 4 bit radar data, but over the last 10 years there have been significant upgrades to the WSR-88D radar network. In 2003, radar levels and resolution were significantly improved with the implementation of Build 5.2.1 for the Advanced Weather Interactive

Processing System (AWIPS). All reflectivity and velocity products were upgraded to 8 bit, which allowed for 256 data levels (as opposed to only 16 levels in the 4 bit era). The resolution also significantly improved with an upgrade to 0.25 km (0.13 n mi) by 1 degree. With this upgrade, it was now possible to view the exact values of strong velocity pixels, as values of up to 123 kts were able to be evaluated. V_r values topped out at 64 kts within the 4 bit data, which prevented the exact strength from being determined. While the resolution was an improvement in the radial direction (from 1 km to 0.25 km), it remained the same in the azimuthal direction. It wasn't until super resolution radar data was available with RDA/RPG Build 10.0 in 2008 when the azimuthal resolution increased to 0.25 km vs. ½ degree. This increase in azimuthal resolution reduced the problem of beam spreading (see Figure 2 for the example of this effect using non-super resolution data) and removed the need to normalize D from the Lapenta et al. (2000) study for range, as adjacent gate to gate pixels remain at most 0.926 km (0.5 n mi) apart up to 111 km (60 n mi) from the radar.

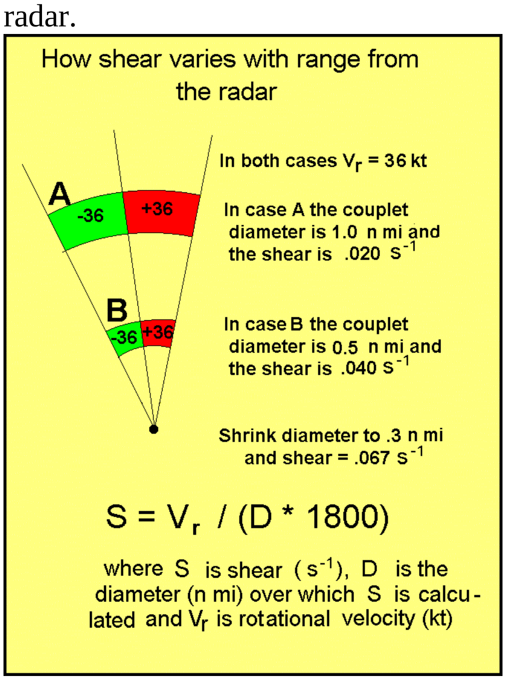

Figure 2: A description of how shear varies with range from the radar. Beam spreading causes shear values to change over distance. Because of this, shear must be normalized to account for range. Graphic courtesy of LaPenta et al. (2000).

As a result of these updates, one of the goals of Collaborative Science Technology and Applied Research (CSTAR) project IV was to update the nomogram for use with the new higher resolution radar data. In addition, Normalized Rotation (NROT) from Gibson Ridge Software's GR2Analyst was examined to assess its utility in helping to predict tornadoes. These updates along with the tornado climatology should allow a forecaster to make speedy and more accurate decisions in regard to tornado prediction.

2. Data and methodology

Tornadoes were examined between 1980 and 2012 across the Northeastern United States with data from *StormData (*US Department of Commerce 1980-2013). The date, location, strength, and time of occurrence were all recorded into spreadsheets. Fatalities, injuries, and damage estimates were also recorded as well. A total of 1037 tornadoes were examined in all.

41 storms between 2003 and 2013 were examined on the Weather Event Simulator (WES). Storm-relative motion was examined in both the plan view and vertical cross-sections, using the Four-Dimensional Storm Investigator (FSI) tool in AWIPS. The majority of the tornadic storms were in or near the NWS at Albany County Warning Area (CWA) due to limited radar data available. Radar data from KENX (East Berne, NY) was primarily used for this study, although some radar data from KBGM (Binghamton, NY) and KOKX (Upton, NY) were also utilized. Additional tornadic storms from this time period were

not included in the study due to unavailable radar data or a lack of signal on radar due to the tornadic storm being below the beam or blocked by terrain. For storms from 2003-08, the previous methodology from the LaPenta et al. study was used for calculating D. However, from 2008 onward, D was set to 0.926 km (0.5 n mi) for all storms within 111 km (60 n mi) of the radar site. If storms were beyond 111 km (60 n mi) from the KENX radar, there was an adjacent radar from another site (such as KOKX or KBGM) that allowed for a closer range. Figure 3 shows the area within 111 km (60 n mi) of the KENX radar. Of the 41 storms examined, 25 of them were from 2008-13. All 41 storms were ranked between F0/EF0 and F2/EF2. In addition, 11 null cases were also examined. These null cases were times when mesocyclones occurred and tornado warnings were issued, but no tornadoes were reported or confirmed.

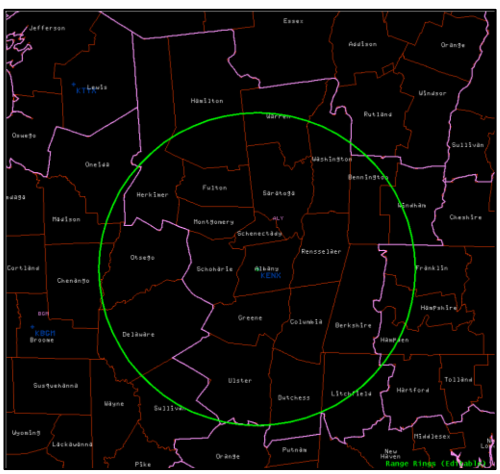

Figure 3: Area within 60 n mi of the KENX radar near the Albany CWA. Within this circle, gate to gate radar pixels are located within 0.5 n mi of each other using 8 bit super resolution radar data.

In addition, 82 tornadic storms from 2003-13 throughout the Northeastern United States were examined using the Gibson Ridge Software's GR2Analyst. The domain for the Northeastern United States was the same as the LaPenta et al. study. 25 null cases from 2008-12 were also examined. For each case the storm's NROT values were noted. As noted in Lemon and Umscheid (2008), the GR2Analyst software uses an algorithm to determine the normalized rotational value that is range independent. NROT values are unitless and range from -5 to +5. Counter-clockwise (clockwise) rotation is valued positive (negative) (www.gr2levelx.com). According to the GR2Analyst user guide documentation, values of over 1.0 are considered significant and 2.5 are considered extreme. NROT values were recorded for all tornadic storms at the time of tornado formation, as well as up to three radar scans before the tornado developed. For the null cases, the NROT value at the time of tornado warning was recorded, as well as up to three scans prior to the warning time issuance.

3. Tornado climatology results

Figure 4 shows the number of tornadoes broken down by Weather Forecast Office (WFO) CWA. As expected, the total number of tornadoes was higher for the southwestern corner of the domain as compared to the far northern and eastern areas. Also, mountainous and low-populated areas (such as in the Burlington and Caribou CWAs), had fewer tornadoes than more populated areas (such as the Mount Holly CWA).

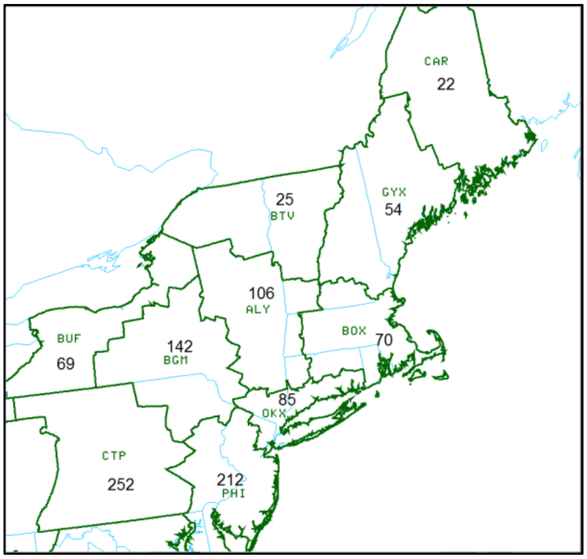

Figure 4: Number of tornados between 1980 and 2012 broken down by WFO CWA for the Northeastern United States.

When broken down for the Albany CWA, tornadoes occurred generally between the months of May and August, as shown in Fig. 5. The peak in tornado occurrence across eastern NY and western New England occurred in the month of July. However, a few tornadoes have occurred as early as April and as late as November. There were no reports of tornadoes in the core winter months of December through February and none reported in the month of March, which is still usually dominated by cold and stable conditions as well.

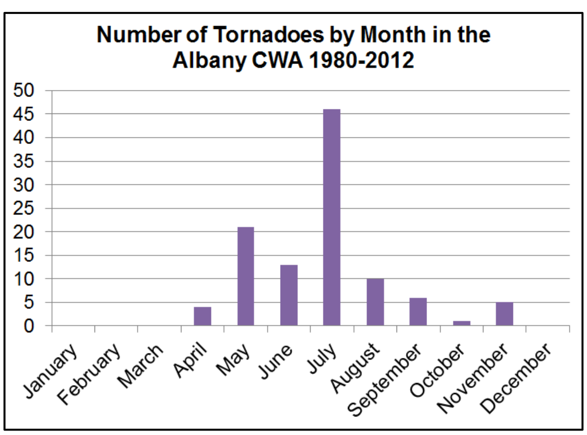

Figure 5: Number of Tornadoes by month in the Albany CWA from 1980 to 2012.

As expected, tornadoes have a tendency to form in the afternoon and early evening hours, with the majority of reported tornadoes between 12:00 and 20:00 Eastern Standard Time (EST). Figure 6 shows the times in EST for all tornadoes that have formed between 1980 and 2012 in the Albany CWA. Although very rare, there have been reported tornadoes in the early morning hours in the Albany CWA.

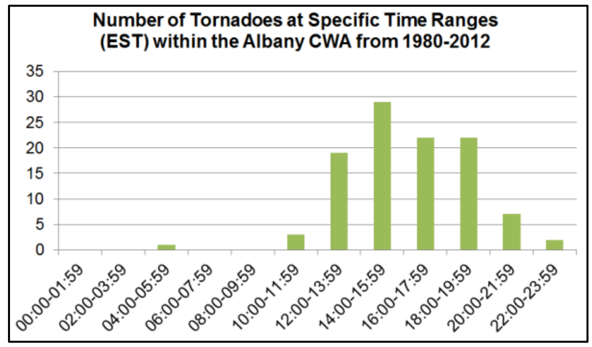

Figure 6: Number of Tornadoes by Time in EST for the Albany CWA from 1980 to 2012.

Figure 7 shows the strength of the reported tornadoes for the Albany CWA between 1980 and 2012. Storms are generally on the weaker side of the scale, with the majority being F0/EF0 and F1/EF1. While no F5/EF5 tornadoes were recorded in the climatology, there were a few F4/EF4 tornadoes, which show that violent tornadoes have occurred in this region in the recent past. This further shows the important need for having accurate methods for predicting tornadic storms.

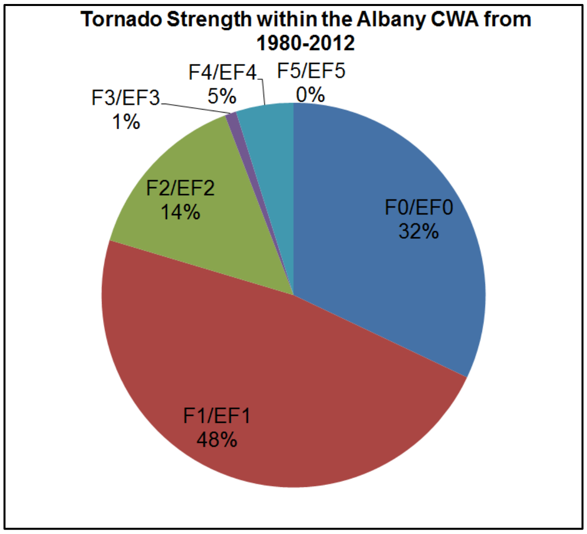

Figure 7: Strength of Tornadoes for the Albany CWA from 1980 to 2012.

4. Updated V-R Shear study results

Figure 8 displays the results of the updated V-R Shear study for 41 tornadoes examined between 2003 and 2013. It is recognized that the 8 bit data before and after the super-resolution upgrade in 2008 may exhibit some differences, but this was not deemed as significant as the differences from 4 bit to 8 bit radar data and thus all 8 bit data is combined using the methods described in the prior section. Similar to the LaPenta et al. study, high values of S and V_m were highly correlated with the occurrence of a tornado, including the majority of the F2/EF2 tornadoes that were examined in the study. Despite the increase in resolution, there still was little correlation between weaker values of S and V_m, as seen in Group I in Fig. 8. While the majority of the null cases had lower values, there were some tornadoes (mainly weak) as well. As a result, the best signal is found when high values of S are also occurring with high values of V_m. High values have been shaded in the darker orange background area of Group III within Fig. 8.

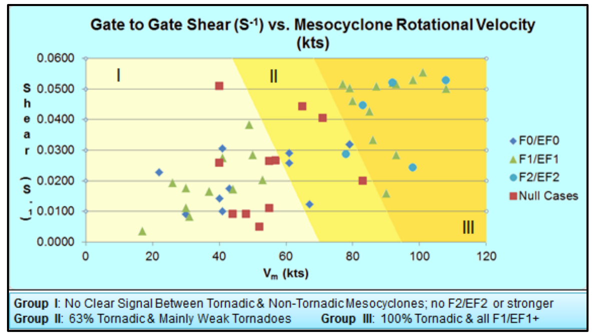

Figure 8: Gate to gate shear vs. Mesocyclone Rotational Velocity based off 41 tornadoes in or near the Albany CWA from 2003 to 2013. D was set to 0.5 for all storms from 2008 to 2013. The previous study methodology was used for D for events between 2003 and 2008.

Table 1 shows the results of the NROT portion of the study. For the tornadic storms, the average 0.5° NROT value at the time of tornado formation was 0.90. The median value was 0.81. At three scans prior to tornado formation, which is about 10-15 minutes based on the Volume Coverage Pattern (VCP) in use at the time, the average value was 0.72 and the median value was 0.73.

Table 1: Average and median 0.5° NROT values for both 82 tornadic and 25 null cases between 2003 and 2013.

NROT Value	**Average**	**Median**
Time of tornado	0.90	0.81
-1 scan before tornado	0.85	0.81
-2 scans before tornado	0.81	0.81
-3 scans before tornado	0.72	0.73
Null Cases		
Nulls at time of warning	0.74	0.71
Nulls -1 scan before warning	0.77	0.79
Nulls -2 scans before warning	0.70	0.77
Nulls -3 scans before warning	0.69	0.65

In contrast, the average value of the non-tornadic mesocyclones from the null cases was 0.74 at the timing of warning issuance. The median value was 0.71. At three scans prior to tornado warning issuance time (about 10-15 minutes based on the VCP in use at time), the average value was 0.69 and the median value was 0.65.

5. Examination of 4 September 2011

A warm and humid environment ahead of an approaching frontal boundary led to the development of thunderstorms across eastern NY on 4 September 2011. As two individual storms collided across the Mohawk Valley, enough low-level helicity was in place for the development of a tornado. Rated EF1 by a NWS Storm Survey, the tornado was on the ground for 15 minutes between 2120 UTC and 2135 UTC (U.S. Department of Commerce 2011). After forming in the town of Florida in Montgomery County, NY, the tornado was nearly a half-mile wide as it passed through the hamlet of Cranesville, NY with maximum estimated winds of 49.17 ms^{-1} (110 MPH). The tornado crossed into Schenectady County, causing damage in the town of Glenville before dissipating, after a track of about 11 km (7 mi).

This tornadic storm was examined with both 4 bit and 8 bit radar data to see the differences between the two products. Figure 9 shows a comparison between 4 bit and 8 bit 0.5° storm-relative motion (SRM) at 2123 UTC 4 Sept 2011 over eastern Montgomery County, NY, which was several minutes after the tornado developed. With this storm being within 48 km (30 n mi) of the radar site, the couplet was measured with a D of 0.926 km (0.5 n mi) with both the 4 bit and 8 bit super-resolution data. The better resolution of the 8 bit super-resolution data showed the structure of the tornadic couplet more clearly than the blocky, 4 bit data. There was also a difference in values, as the 4 bit V_r was 43.0 kts, while the 8 bit super-resolution was 53.9 kts. This caused a difference in the calculated S values. The S value was 0.0450 s^{-1} for the 4 bit SRM, as compared to 0.0626 s^{-1} for the 8 bit SRM. These differences between the 4 bit and 8 bit show how the warning meteorologist cannot use the nomogram of the original study with the upgraded radar data.

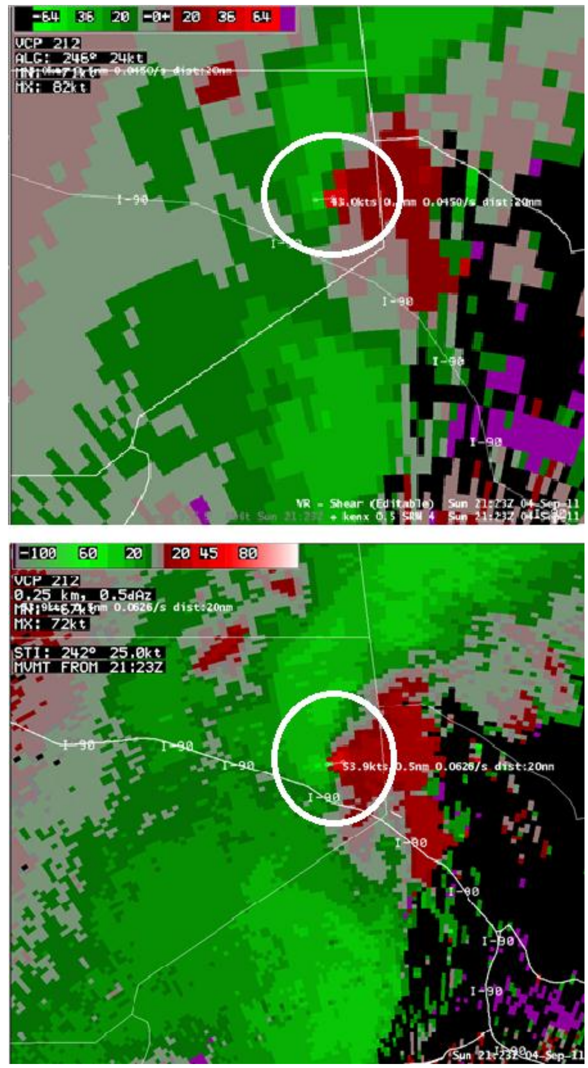

Figure 9: A comparison of 4 bit (top) and 8 bit super-resolution (bottom) 0.5° storm-relative motion (SRM) radar data from 2123 UTC 4 September 2011. The tornadic couplet structure is more detailed in the 8 bit high resolution image. In addition, the V_r value is stronger based off the 8 bit super resolution data.

Figure 10 shows a cross-section of the tornadic thunderstorms at 2123 UTC, which is three minutes after the tornado developed. The low-level tornadic couplet is easily visible at the bottom of the image. At the same time, a mesocyclone is present in the mid-levels, at about a height of about 4500 to 6000 m. The maximum value of this mesocyclone (V_m) was recorded to be about 55 kts.

At the time of tornado formation, NROT was 1.40, which is well-above both the average and median values, as calculated in the study. In addition, at about 10 minutes before tornado formation at 2109 UTC, NROT was 0.89, which is also above the study's average and median values for two scans prior to tornado formation.

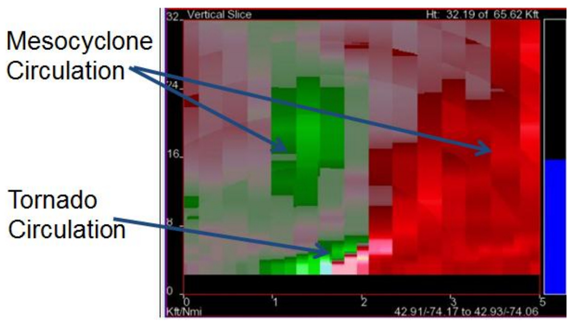

Figure 10: A vertical cross-section of the tornadic thunderstorms from 2123 UTC 4 September 2011 from FSI. Both the mid-level mesocyclone and low level tornadic circulation are visible in the image. V_m was calculated to be 55 kts.

6. Examination of 29 May 2013

A warm front moved through the region early in the day on 29 May 2013. Although the day began off cloudy, breaks of sun occurred by early afternoon, which allowed the atmosphere to become moderately unstable. As an upper level shortwave moved from southern Ontario towards upstate NY, convection developed across western and central NY, due to a contribution from a lake breeze boundary off Lake Ontario. This convection spread eastward as it moved along an equivalent potential temperature gradient that was aided by a differential heating zone that had set up across the Mohawk Valley and into the Capital Region.

As the thunderstorms began to organize into a line, a supercell thunderstorm just ahead of the developing line began to rotate as it approached the eastern Mohawk Valley. This supercell took on a classic hook echo shape in reflectivity on the 0.5° tilt (Fig. 11) and a tornado formed at 2247 UTC near the hamlet of Scotch Bush in the town of Florida in eastern Montgomery County.

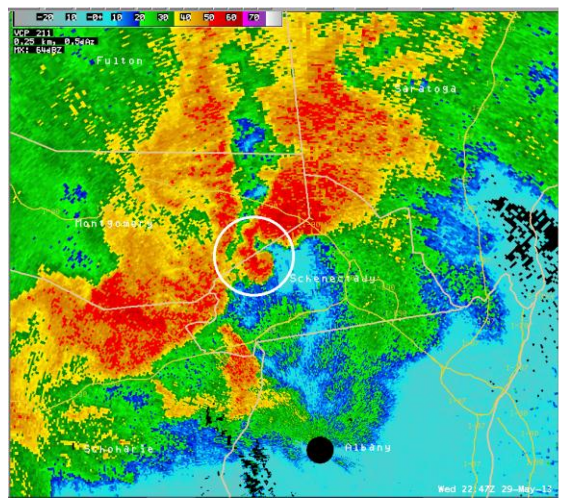

Figure 11: 0.5° reflectivity from a supercell thunderstorm in eastern Montgomery and western Schenectady Counties ahead of a developing squall line at 2247 UTC 29 May 2013.

The tornado tracked eastward into western Schenectady County, passing through the hamlet of Mariaville. At this point, the tornado produced damage nearly one mile wide in diameter and reached its strongest strength of EF2 with maximum winds estimated at 55.88 ms^{-1} (125 MPH) (U.S. Department of Commerce 2013). The tornado continued to track eastward and slowly weakened. It dissipated once it reached the western portion of the city of

Schenectady at 2304 UTC, after a track of 21 km (13 mi).

Figure 12 shows an image of 8 bit, super resolution 0.5° SRM from the thunderstorm at the time of maximum tornado strength (2252 UTC). Using a D of 0.926 km (0.5 n mi), V_r was calculated to be 48.0 kts for adjacent pixels across the tornadic couplet. Using the V-R Shear equation, S was calculated to be 0.0527 s^{-1}.

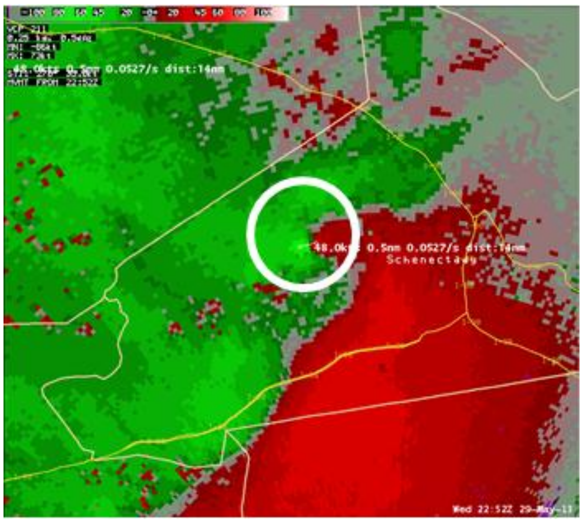

Figure 12: 0.5° SRM image of the tornadic couplet at 2252 UTC 29 May 2013 across Schenectady County, NY.

When examining a vertical cross-section of SRM, both the tornadic rotation and mesocyclone circulation are both evident. Figure 13 shows a 2-D cross-section from FSI. With very strong values in both the inbound and outbound velocity, V_m is calculated to be 108 kts at 2252 UTC. Strong inbound velocities behind the storm are indicative of the descending rear inflow jet.

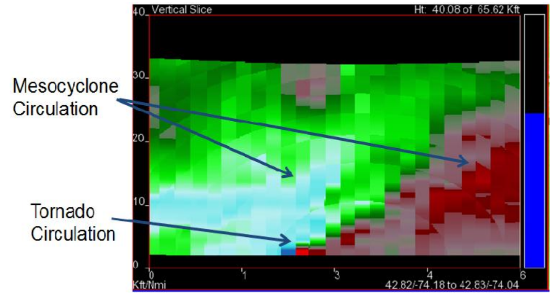

Figure 13: Cross-section of SRM from 2252 UTC 29 May 2013 across Schenectady County, NY.

Figure 14 shows the 0.5° NROT values for the thunderstorm as viewed in the GR2Analyst software at 2247 UTC, which is the time of tornado formation. The maximum value was 1.36, which is well-above both the average and median values, as calculated in the study. In addition, NROT values were as high as 0.85 at 3 scans prior to tornado formation at 2232 UTC.

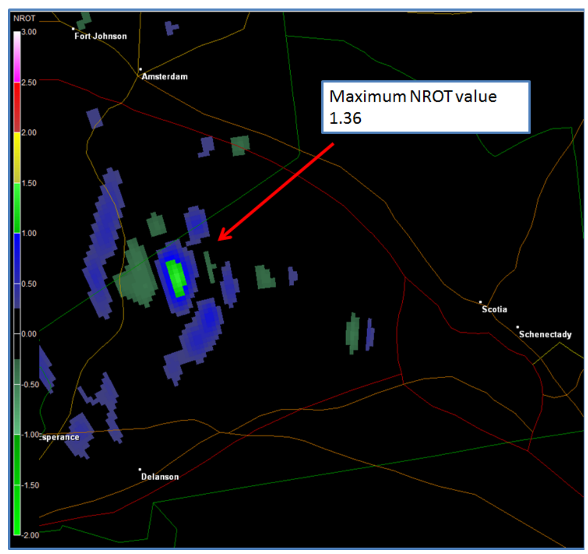

Figure 14: 0.5° NROT from GR2Analyst at 2247 UTC 29 May 2013 in eastern Montgomery County, NY.

7. Conclusions

There are significant differences between the values for both V_r and S between 4 bit and 8 bit radar data. As seen in the 4 Sept 2011 case, the increased resolution allowed for more detail when examining the tornadic couplet, specifically when determining the strength and the rotation. The value of V_r was nearly 17 kts higher when measured with the 8 bit, high resolution radar data.

Using the updated nomogram in Fig. 8, the 4 Sept 2011 tornado would fall somewhere near the border of Group I and II, when calculated with S of 0.0626 s^{-1} and V_m of 55 kts. While not as clear cut as some other storms, this would give the warning forecast some increased confidence in the possibility of a tornadic storm.

The tornadic event on 29 May 2013 was another recent example of the use of the new nomogram. When using the 8 bit high resolution data, S was 0.0527 s^{-1} and V_m was 108 kts. This would put this EF2 tornado solidly in Group III in the updated nomogram in Fig. 8. A warning meteorologist would have high confidence based on the study that formation had occurred with this storm.

One of the more important changes going from the 4 bit data to 8 bit, super resolution data is the need to no longer normalize for range for within 111 km (60 n mi) of the radar. Having to figure out what to set D based on the storm's location was an extra time consuming step. In a warning situation, every second is precious time that is needed for the protection of life and property. The removal of this need allows for faster analysis of values, which can lead to an improvement in lead time and a better protection of life and property.

In addition, the use of NROT data can also help increase confidence, even up to several scans before the tornado develops. Figure 15 shows a box and whisker plot for NROT values at the time of tornado formation and up to three scans before the tornado develops (about 10-15 minutes depending on which VCP the radar is being used). This chart can be useful to operational meteorologist when making a warning decision. As noted in Banacos (2011), the median level gives a better level of the central tendency of the dataset. Similar to what was done in a local hail study (Frugis and Wasula 2011), the median level can be used a starting point for warning consideration. In addition, the 25th quartile value can be used a cautionary level, letting the warning meteorologist know that this is something worth investigating further.

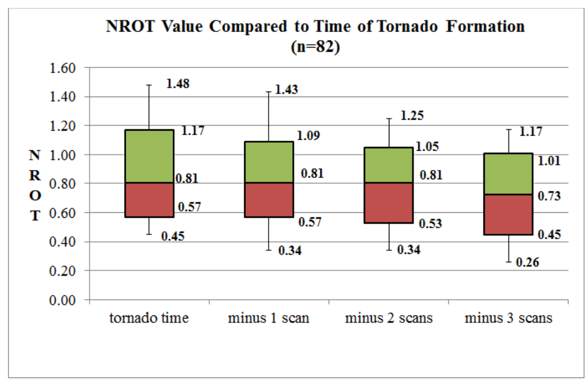

Figure 15: Box and whisker plot for 0.5° NROT values taken at the time of tornado formation and up to three radar scans before the tornado develops.

In general, the results of the updated study closely parallel the work completed by LaPenta et al. in 2000. While the weaker tornadoes and null case mesocyclones continue to show similar results in S and V_m, stronger tornadoes continue to show a signal with high levels of S and V_m. As a result of this study, the V-R Shear technique can continue to be applied in an operational setting using the latest radar technology. When combined with other new methods, such as methods of using dual-polarization products to find debris signatures, detection of tornadic activity will continue to be improved, providing the public with more confident warning products and an increase in safety.

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