CRARP 24-06

USE OF COMBINED SHEAR AND SPECTRUM WIDTH IN TORNADO DETECTION

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1. Introduction

WSR-88D operators have been trained to look for tornado signatures using base reflectivity and storm relative motion. Despite improvements stemming from the implementation of the WSR-88D network, these conventional signatures are not always evident in tornadic situations. At other times, these signatures may exist without tornadic development, even when environmental parameters appear favorable. Research into pre-storm environment and its relation to tornadoes will undoubtedly continue to advance meteorological understanding of the subject. However, radar detection of tornadoes remains essential to the ultimate goal of protecting life and property. Therefore, the radar team at WFO Hastings (GID) decided to evaluate a method of enhancing tornado detection from a radar perspective using spectrum width and combined shear.

Two previous studies of spectrum width and combined shear were consulted for reference values (Buller and Mentzer 1998; Wilkens 1997). The radar team chose spectrum width of 6 ms^{-1} (12 kt), and combined shear of .0080 s^{-1} for initial values to define areas needing further investigation. An analysis of several events detected by the GID WSR-88D (KUEX) was conducted to demonstrate the benefits and limitations of utilizing spectrum width and combined shear products. The primary methodology was to use spectrum width and combined shear in a four-panel with base reflectivity and storm relative velocity map (SRM). In some cases, these products were consulted in real-time, but their use in the warning process will not be documented here. The environment was favorable in each episode for supercells, mini-supercells, or squall lines, with potential for tornado development; but discussion of pre-storm environment will not be included in this paper.

2. Definitions

Spectrum width is a measure of the velocity dispersion within a sample volume. In other words, it is a measure of the variability of the velocity estimates. The spectrum width product is displayed in eight data levels as a radial image of mean radial velocity spectrum widths. Large spectrum widths are related to turbulence intensity and to mean wind shear across the beam. As spectrum width is typically a noisy product, the GID radar team decided to use the coarsest resolution, 1 km x 1.0˚. Corresponding with this resolution is a range of 230 km, more than adequate to cover the GID county warning area at the lowest elevation angle (0.5˚).

The heavily filtered combined shear product was adopted to offer a complementary view to the noisy spectrum width product. The combined shear algorithm was originally developed for detection of larger scale shear associated with fronts. It uses dealiased 0.25 km resolution mean radial velocity as input, then combines filtered radial and azimuthal shear into a single value displayed in Cartesian coordinates. According to the Operational Support Facility (OSF) (1997), quantitatively,

$$\text{Combined Shear} = [(\text{Radial Shear})^2 + (\text{Azimuthal Shear})^2]^{1/2}$$

where radial shear is the velocity difference along a radial divided by the length of the radial, and azimuthal shear is velocity difference along an azimuth divided by the azimuthal length. (Figure 1)

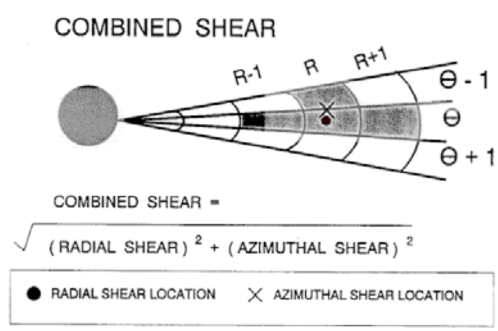

Figure 1 - OSF Diagram of Combined Shear

Radial and azimuthal shear are calculated using up to a 25 point filter to blend out noise. GID maintained the default nine point filter with 1 km x 1 km resolution NOAA (1991). It was thought that less filtering would render the combined shear product noisy, similar to spectrum width, while more filtering would smooth the data to a point such that small areas of turbulence would be lost or misplaced. While the default elevation for the combined shear algorithm is the 1.5˚, KUEX calculated the combined shear at 0.5˚, surmising that the lower elevation angle would yield quality data farther from the radar.

3. Events

2 May 1999

Mini-supercells produced 10 confirmed tornadoes over south central Nebraska during the late afternoon of May 2. Combined shear was not on the KUEX routine product set (RPS) list for this event, but spectrum width was examined to determine its performance during an event of weaker rotational velocity. Most of the storms were within 90 km of the KUEX and were well-defined with "hooks", or tight rotational velocities greater than 20 ms^{-1} (39 kt). However, the radar signature of the initial tornado near the Gosper/Furnas County line was considerably weaker, probably due to sampling limitations with beam height of 2750 m at 125 km. Rotational velocity was 13 ms^{-1} (26 kt) over a diameter of 3 km, which is sufficient rotation for tornado development in the organizational stage of a mini-supercell (Andra et al. 1995). A tight reflectivity gradient with a small appendage on the south side of the northward moving storm, along with spectrum width values of 8 ms^{-1}(16 kt) provided additional indications of a developing tornado (Figure 2). A tornado was confirmed in this area over Furnas County resulting in F0 damage. The storm produced another tornado causing F1 damage as it moved further into Gosper County. Rotational velocity at that stage reached a maximum of 21 ms^{-1} (41 kt) with a 3 km diameter 25 minutes later, while spectrum width maintained its display of 8 ms^{-1}(16 kt) for all but one volume scan.

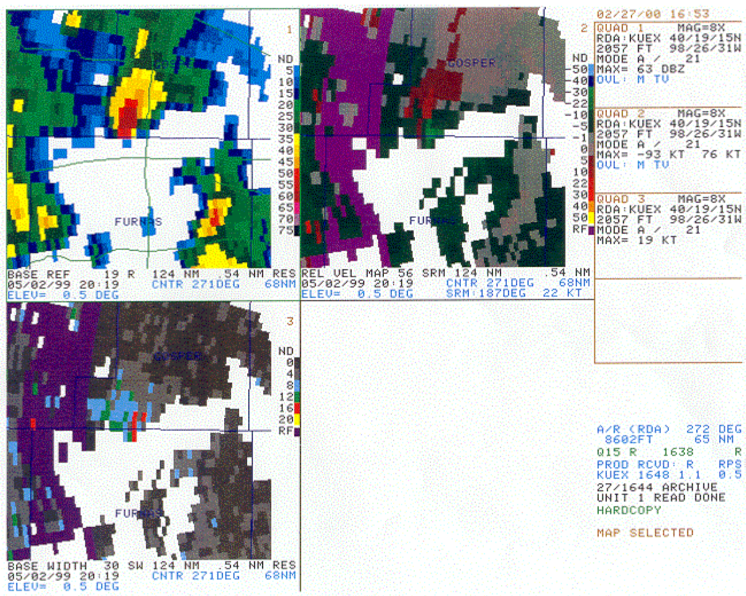

Figure 2 - 2019 UTC Reflectivity, Storm Relative Velocity and Spectrum Width

15-16 May 1999

The Rooks County, Kansas tornado of May 15 was the initial event with combined shear on the RPS list. Rapid tornadogenesis was the hallmark of this F1 event. SRM coupled inbound velocity of 26 ms^{-1} (50 kt) with 7 ms^{-1} (15 kt) outbounds, to produce rotational velocity of 17 ms^{-1}(32 kt), which is near the upper threshold for mini-supercell tornadoes (Andra; Grant and Prentice 1996). Combined shear initialized the event with .0090 s^{-1}, which increased to .0100 s^{-1} the next volume scan. SRM showed 16 ms^{-1} (31 kt) rotational velocity at 2353 UTC; however, diameter between maximum pixels rose from 2 km (1.2 nm) to 4 km (2.3 nm) over the two scans (Figure 3). Spectrum width increased from 6 ms^{-1} (12 kt) to 8 ms^{-1} (16 kt) from 2347 UTC to 2353 UTC.

The 2359 UTC scan showed a decrease in magnitude of all parameters, except spectrum width. SRM computed 13 ms^{-1} (26 kt) of rotational velocity over 4km (2.0 nm), combined shear decreased to .0080 s^{-1}, but spectrum width maintained 8 ms^{-1} (16 kt) as reports of the tornado southwest of Stockton arrived. The downward trend in rotational velocity continued with the 0005 UTC scan: 11 ms^{-1} (22 kt) over 4 km (2 nm). Spectrum width decreased to 6 ms^{-1} (12 kt), but combined shear registered an increase with a pixel of .0150 s^{-1}, as more reports confirmed a tornado to the southwest of Stockton (Figure 4). All parameters decreased with the 0011 UTC scan as the tornado rapidly disintegrated. The beam height at 0.5˚ for north central Rooks County is around 2900 m at 130 km. This initial event exemplified the potential of combined shear and spectrum width when SRM did not display persistent, strong rotation.

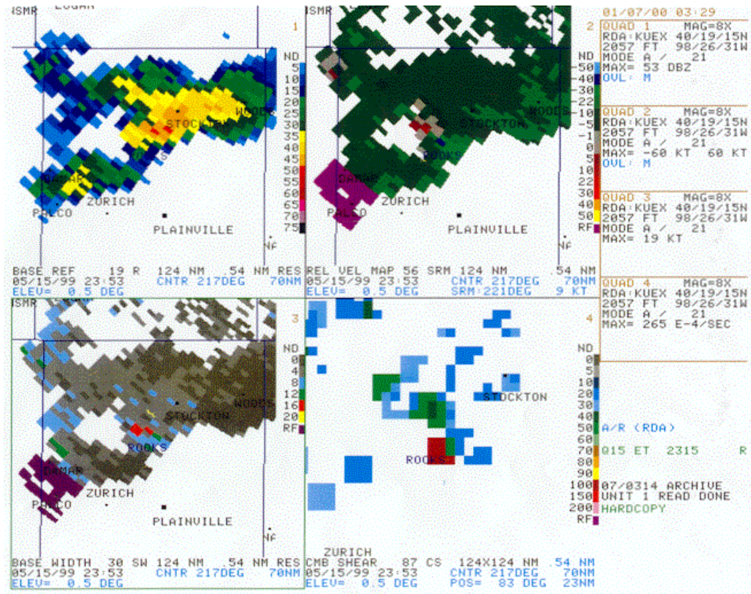

Figure 3 - 2353 UTC Reflectivity, Storm Relative Velocity, Spectrum Width and Combined Shear

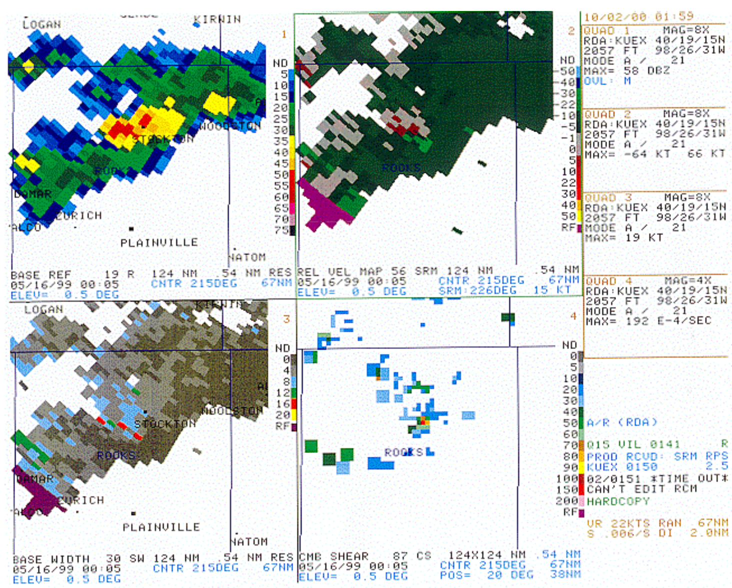

Figure 4 - 0005 UTC Reflectivity, Storm Relative Velocity, Spectrum Width and Combined Shear

30-31 May 1999

A southward moving supercell thunderstorm produced an F2 tornado north of Lexington in Dawson County, Nebraska on the evening of May 30. Conventional signatures, including two scans of 0.5° rotational velocity of 21 ms^{-1} (40 kt) over a 2 km diameter, were sufficient to make the initial threat apparent. Combined shear helped identify the area with values of .0100 s^{-1} to .0200 s^{-1} as the event evolved. While spectrum width generally displayed a broad, noisy pattern, values were as high as 8 ms^{-1} (16 kt) (Figure 5).

SRM still showed convergent rotation with 15 ms^{-1}(30 kt) of rotational velocity as the storm approached Lexington; however, the tornado lifted about 2 miles north of town. Combined shear and spectrum width were perhaps more indicative of the trend at that time as values decreased to .0080 s^{-1} and 6 ms^{-1}(12 kt), respectively. The storm pulsed several times as it continued southward into Phelps County. Nearly an hour after the initial tornado, at 0102 UTC, the radar algorithm defined a tornado vortex signature (TVS) over northwest Phelps County. SRM showed an increase in rotational velocity from 14 ms^{-1} (26 kt) at 0057 UTC to 16 ms^{-1} (31 kt) at 0102 UTC as reflectivity displayed a pronounced hook. Spectrum width and combined shear indicated an opposite trend; decreasing from 8 ms^{-1}(16 kt) to 6 ms^{-1} (12 kt), and from .0090 s^{-1} to .0080 s^{-1}respectively, over the two scans (Figure 6). Spotters were in place due to the tornadic history of the storm; however, no tornado was sighted over northwest Phelps County.

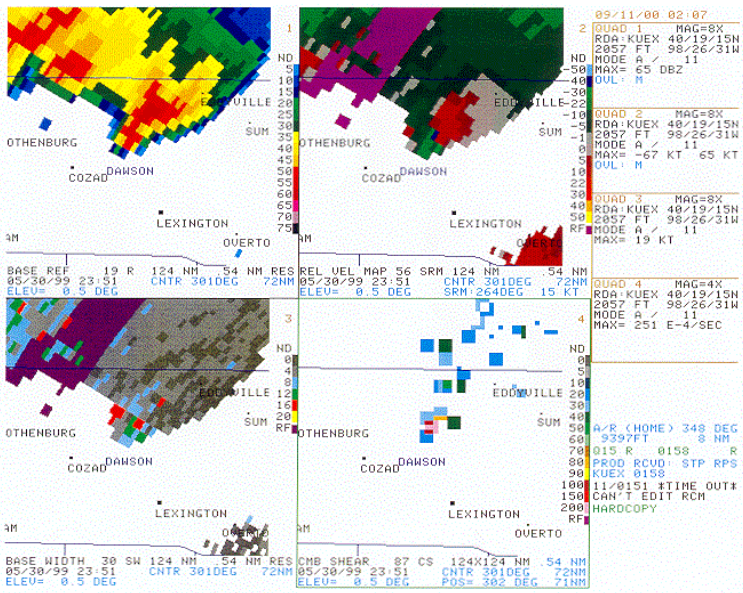

Figure 5 - 2351 UTC Reflectivity, Storm Relative Velocity, Spectrum Width and Combined Shear

30 June 2000

The June 30 event will be remembered over parts of south central Nebraska and north central Kansas for extensive damage caused by large hail, driven by straight-line wind in excess of 45 ms^{-1} (86 kt). However, spotters did report three tornadoes that day over Norton and Rooks Counties in Kansas. The first was sighted 9 km west of Logan, in Phillips County, at 0030 UTC. Velocity displays were plagued by dealiasing problems, which also contaminated combined shear, as the algorithm registered maximum values along the shear axis for several scans before the report of the tornado. Combined shear did isolate the turbulence in the report area at 0024 UTC with values of .0200 s^{-1}, and was supported by 8 ms^{-1} (16 kt) spectrum width readings on the southwest edge of this storm (Figure 7). Beam height over this location was 2835 m for the 0.5° scan. The high values persisted, and became more extensive in area during the 0030 UTC scan (Figure 8). A small tornado causing F0 damage was confirmed; however, this case illustrates why combined shear and spectrum width need to be complemented by reflectivity and SRM in a four-panel. The filtered combined shear successfully displayed the threat area, although the reliability of the data is questionable due to improper dealiasing of mean radial velocity.

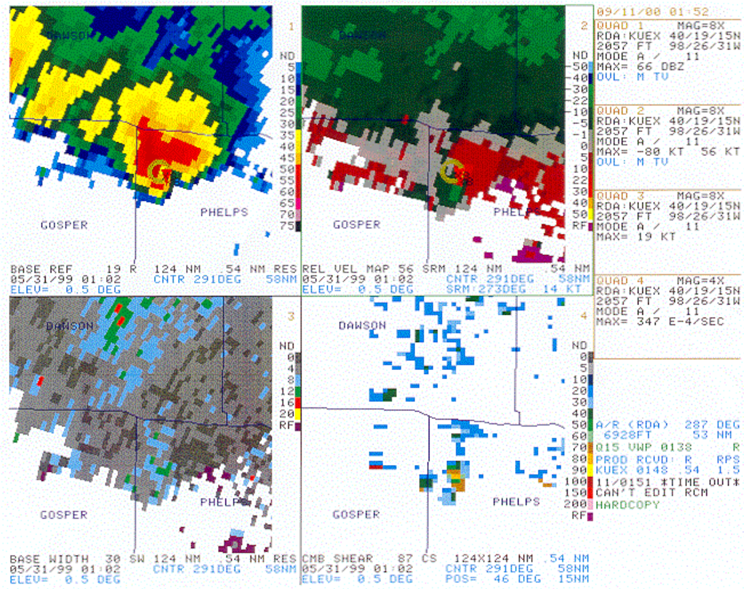

Figure 6 - 0102 UTC Reflectivity, Storm Relative Velocity, Spectrum Width and Combined Shear

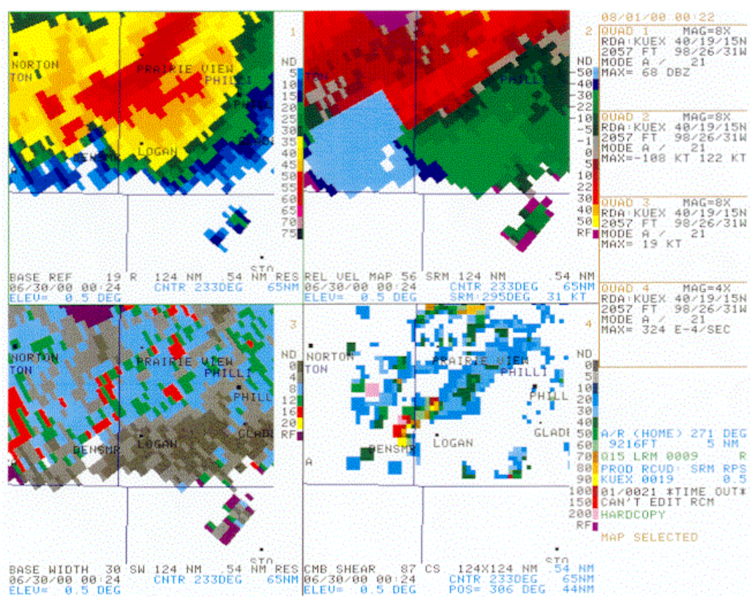

Figure 7 - 0024 UTC Reflectivity, Storm Relative Velocity, Spectrum Width and Combined Shear

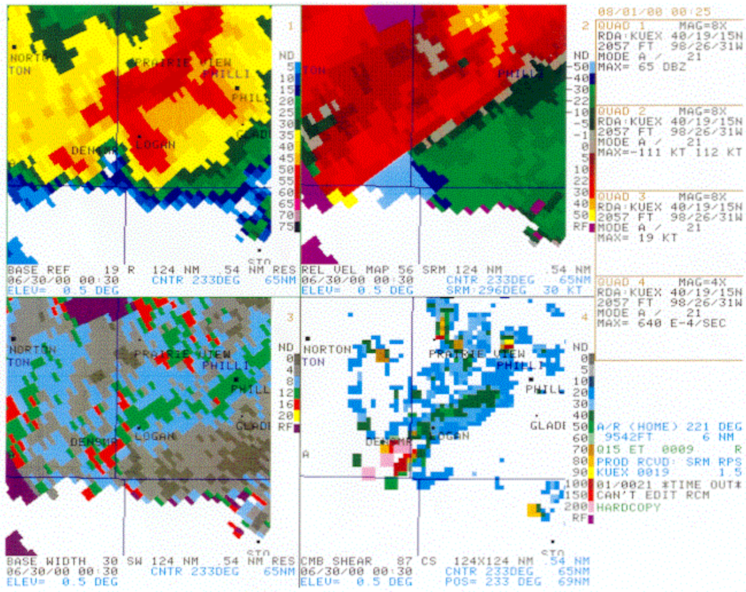

Figure 8 - 0030 UTC Reflectivity, Storm Relative Velocity, Spectrum Width and Combined Shear

18 August 1999

Examination of the August 18 squall line illustrates another type of event in which use of spectrum width and combined shear can be advantageous. Combined shear and spectrum width may help radar operators focus on areas of magnified damage, or brief tornadoes, by better defining the shear along eddies in the squall line. Obviously, operators need to be especially alert in an environment favorable for tornadoes, as powerful thunderstorm lines will generate numerous areas of vigorous shear. Isolated tornadoes were reported by the public during this episode, however none were confirmed in the darkness and confusion of widespread wind damage.

The first example is from early in the event, when the line of thunderstorms was crossing the northwestern counties of the GID county warning area. A portion of the line accelerated over Dawson County, Nebraska causing widespread wind damage on an axis through Gothenburg, Cozad, and Lexington, with one of the more impressive reports being of cars moved around a Cozad parking lot. The 0.5˚ reflectivity trend was indicative of the threat, but spectrum width distinguished the bulge with 8 ms^{-1} (16 kt) values. By 0154 UTC, SRM showed a small area of 51 ms^{-1} (100 kt) shear on the north side of the salient region, while combined shear registered .0200 s^{-1} (Figure 9). No tornadoes were reported from these rural areas north of Lexington, but the products suggested the potential for magnified, localized wind damage.

The second example occurred approximately 33 km from the radar, so resolution due to poor sampling was not a factor. However, algorithm overload certainly was a factor as numerous mesocyclones and TVS's were defined along the edge of the strong gust front as the thunderstorm line moved toward the radar. Widespread wind damage continued to occur as the storms approached Adams County, Nebraska. In Adams County, large trees were downed in Kenesaw and 3 miles south of Juniata, where a tornado was reported. The combined shear algorithm calculated a broad area of .0100 s^{-1} in the shear zone as the line moved into Adams County, then increased to .0150 s^{-1} at 0345 UTC, when the storms were about halfway between the two towns. TVS's were again defined in this area as SRM indicated 5 to 10 ms^{-1} (10 to 20 kt) outbound along the inbound gust front, and reflectivity depicted an appendage on the north side of the bow. Spectrum width showed an 8 ms^{-1} (16 kt) cluster, but the display was becoming noisier with proximity to the radar (Figure 10). Again, no tornadoes were confirmed over these rural areas between Kenesaw and Juniata, but the examination suggests the combined shear and spectrum width displays may be helpful in locating areas of increased damage, if not small tornadoes.

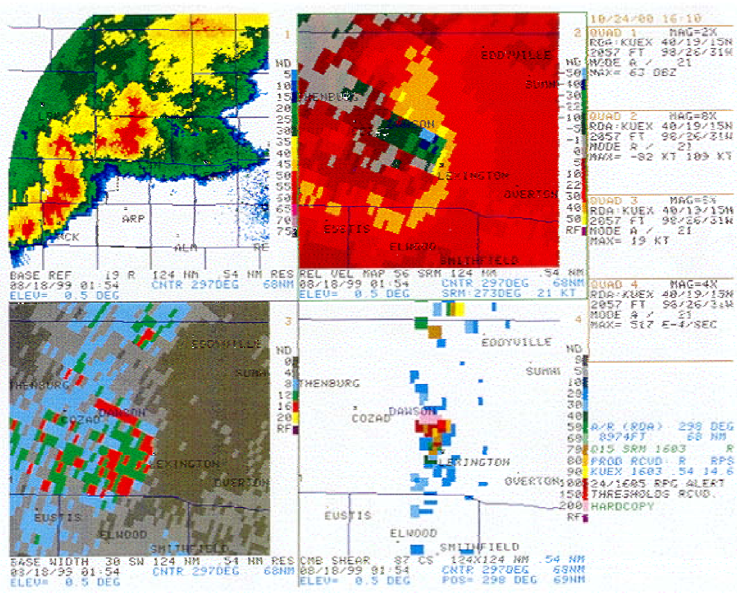

Figure 9 - 0154 UTC Reflectivity, Storm Relative Velocity, Spectrum Width and Combined Shear

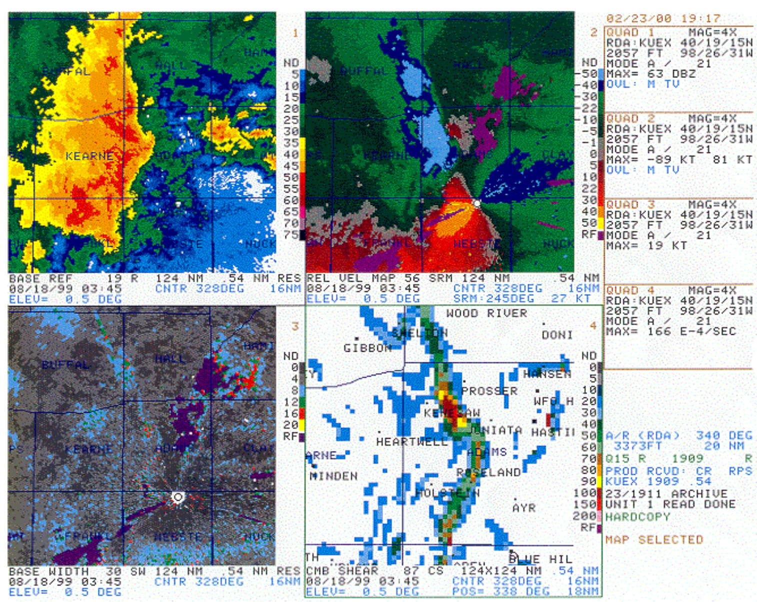

Figure 10 - 0345 UTC Reflectivity, Storm Relative Velocity, Spectrum Width and Combined Shear

4. Conclusions

The GID radar team has found that use of combined shear and spectrum width, in conjunction with base reflectivity and SRM, is beneficial in situations of weak rotation, or those in which poor radar sampling may cause data deficiency or degradation of the WSR-88D algorithms' output. The higher resolution and refined display of combined shear, coupled with the coarse display of spectrum width has aided in identifying areas of enhanced shear in tornadic and straight line wind events.

NWS radar operators are cautioned not to make warning decisions based solely on combined shear or spectrum width displays. These products will yield high values along boundaries, and in non-tornadic turbulent areas of thunderstorms. In addition, high values may be triggered by anomalous propagation and improperly dealiased velocity data. A four-panel display with reflectivity, SRM, spectrum width, and 0.5° combined shear is recommended. In addition, frequent generation of the higher resolution (0.5 km) storm relative region (SRR) should be considered.

The 6 ms^{-1} (12 kt) spectrum width, and .0080 s^{-1} combined shear values are not tornado thresholds, but the trend toward, and beyond these reference values has shown to be an indicator of the high shear found in thunderstorms which produced tornadoes or damaging wind. Spectrum width values of 8 ms^{-1} (16 kt) and combined shear of .0090 s^{-1} were better indicators of tornadic circulations in the events examined, but more research is needed before any attempt is made at establishing a threshold for a particular type of event. Although the combined shear algorithm output yielded helpful data, experimentation with different resolutions and elevation slices is needed before optimum use of the algorithm can be claimed.

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