P2.10 EVALUATION OF A FASTER SCANNING STRATEGY FOR THE WSR-88D COMBINED RANGE ALIASING MITIGATION TECHNIQUES

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1. INTRODUCTION

In 2006, the Radar Operations Center (ROC) sent a survey to all operational WSR-88Ds nationwide. One question asked what upgrades to volume coverage patterns (VCPs) forecasters would like to see. Thirty-three percent of the sites responded that they wanted faster VCPs while another 8 percent said that they wanted more range aliasing (folding) mitigation. To mitigate the range aliasing, the ROC has fielded two algorithms. The first is the Multiple Pulse Repetition Frequency (PRF) Dealiasing Algorithm (MPDA) described by Zittel and Wiegman, 2005. This algorithm was deployed in 2004 as VCP 121. The second, the Sachidananda/Zrnić phase coding algorithm (SZ-2), was fielded in 2007. Its implementation is described by Zrnić et al., 2006. These algorithms have been combined as the Enhanced VCP 121. Together they mitigate the majority of range aliasing but at the cost of added time. As most forecasters want faster VCPs, this study's main focus was to look at removing some of the scans from the Enhanced VCP 121 to see if a faster version could be fielded. This paper shows that, under most circumstances, scans may be removed without operationally degrading velocity products.

2. SCANNING STRATEGIES

In the following sections the original VCP 121 will be referred to as the baseline VCP 121, the Enhanced version described by Zittel et al., 2008, as the 3-Scan Enhanced VCP 121, and the faster version of the Enhanced VCP 121 as the 2-Scan Enhanced VCP 121.

2.1 *Baseline VCP 121*

The MPDA (VCP 121) combines sequential Doppler scans at the same elevation angle that use different PRFs to reliably dealias velocity fields out to about 175 km. At the 2 lowest elevations, 0.5 and 1.5 degrees, a low-PRF surveillance scan if followed by three Doppler scans. The first Doppler scan uses PRF 8 (~1282 Hz), the second scan uses PRF 6 (~1095 Hz), and the final scan uses PRF 4 (~857 Hz). For the elevation angles at 2.4 and 3.4 degrees a batch scan (surveillance and Doppler combined) is first run then two Doppler scans follow. At 4.3 degrees a batch scan is used followed by one Doppler scan. The MPDA mitigates range folding because bins that are range folded in one scan may not be range folded in another scan with a different PRF. At 6.0 through 19.5 degrees the legacy Velocity Dealiasing Algorithm (VDA) is used. The baseline VCP 121 requires 5 minutes 30 seconds to complete an entire volume scan.

2.2 *3-Scan Enhanced VCP 121*

The Enhanced VCP 121 blends both the MPDA and the SZ-2 algorithms. Unlike the baseline VCP 121, the enhanced version uses SZ-2 to mitigate range folding on the first Doppler scan (PRF 8) at the 0.5 and 1.5 degree elevations. SZ-2 extracts weak echoes from strong echoes through advanced signal processing. As with the baseline VCP 121, the next two Doppler scans use PRF 6 and PRF 4. MPDA is then run on the three velocity scans. The 3-Scan Enhanced VCP 121 recovers about 98 percent of the total velocity field out to 230 km. However, this increase in recovered velocity data takes 15 seconds longer than the baseline VCP 121 making the total time to complete one complete volume scan about 5 minutes 45 seconds (Zittel, 2007).

2.3 *2-Scan Enhanced VCP 121*

The 2-Scan version of the Enhanced VCP 121 is similar to the 3-Scan version except that the middle Doppler scan (PRF 6) has been removed from the two lowest elevations. This shortens the time that the Enhanced VCP 121 takes to complete a full volume scan to 5 minutes 15 seconds—a savings of 30 seconds.

3. DATA CASES

Six data cases were collected for this study from the ROC test bed WSR-88D (KCRI) in Norman, OK. Four of these cases involved widespread precipitation that moved though Oklahoma on October 10, October 15-16, November 5-6, and December 29-30, 2006. All of these cases had velocity fields that were fairly uniform and, only infrequently, had velocities that exceeded the Nyquist velocity (maximum measurable velocity) of the highest PRF of about 32 m s^{-1}. Figure 1 shows a reflectivity image for the case from December 29-30, 2006 at 01:12Z about the middle

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of the analysis period. Within 230 km echo areal coverage is about 75 percent. Heavy showers are embedded within the widespread light precipitation. Figure 2 shows a velocity image generated with the 3-Scan Enhanced VCP 121 and Figure 3 shows the 2-Scan Enhanced VCP 121 velocity image for the same time. Little difference is seen between the two velocity images.

The fifth case was a multi-cell cluster of thunderstorms that evolved into a Mesoscale Convective System (MCS) on June 19-20, 2007. This case provided strong winds in a non-uniform velocity field that provided a more rigorous test of the Enhanced VCP 121 than the widespread precipitation cases. Figure 4 shows a reflectivity image at 05:46Z on June 20th. At this time the primary band of strong storms is passing over KCRI and an outlflow boundary is evident just south of the radar. Figure 5 shows the 3-Scan Enhanced VCP 121 image for the same time and Figure 6 shows the corresponding 2-Scan Enhanced VCP 121 image. The two velocity images are nearly identical.

The final case was collected on August 18, 2007 when the remnants of Tropical Storm Erin briefly re-intensified with a well-defined circulation center as it passed through central Oklahoma. This data were evaluated in terms of the volume of velocity data but the velocity field was not scored for dealiasing errors. (This case is not illustrated.)

4. METHODOLOGY

This study used Archive Level 2 data of Enhanced VCP 121 from KCRI. The data were played back through a stand-alone non-operational Radar Product Generator (RPG) twice. The first time velocity products from the 3-Scan version were generated. For the second playback, the MPDA software was modified to ignore the middle (PRF 6) Doppler scan at the two lowest elevations simulating a 2-Scan Enhanced version of VCP 121. (An operational version would, of course, have no time delay between the PRF 8 and PRF 4 scans.) Area and outlier statistics were generated using software programs developed by ROC personnel. The statistical data were then imported into spreadsheet software for further analyses. In addition to the statistical data, the first five cases were examined and scored visually for velocity dealiasing errors.

4.1 *Area Comparisons*

Areal time trends of velocity and range folded data were analyzed on a case-by-case basis at the 0.5 and 1.5 degree angles for any changes in the volume of velocity data that could impact the operational use of the 2-Scan version. Then for each data case, the velocity (VE) and range folded (RF) areas at each elevation were used to compute the fraction of the echo coverage that was velocity data. Multiplying by 100 yields the percent of echo that was velocity data shown as:

$$Pct(VE) = 100 * \frac{\sum_{m=1}^{N} Area(VE)_m}{\sum_{m=1}^{N} Area(VE)_m + \sum_{m=1}^{N} Area(RF)_m}$$

where N is the number of volumes in the data case and m is the individual volume scan. The percentage of area that is range folded is found by subtracting the percentage of usable data from 100 as show:

$$Pct(RF) = 100 - Pct(VE)$$

The averages for the two elevation angles were then averaged to produce a final average percent of usable and range folded data for each case for each version of the Enhanced VCP 121.

4.2 *Outliers*

Next outliers were analyzed. An outlier is identified when its value differs from the average of the surrounding bins. High outlier counts indicate noisy or incorrectly dealiased velocity fields. The number of bins identified as outliers is tabulated for velocity categories from 5 to 30 m s^{-1} incrementing by 5 m s^{-1}. The ratio of the number of outliers in each category to the total number of bins examined, when multiplied by 100, yields the percent of bins in the different outlier categories. An overall average for each outlier category is obtained by computing the average of all volume scans for all cases for the two elevation angles. The data were examined for changes in outlier frequency between the 3-Scan and the 2-Scan versions.

4.3 *Dealiasing Errors*

The final parameter evaluated was velocity dealiasing errors. These errors, seen as discontinuities in velocity that do not fit the surrounding field, can interfere with a forecaster's ability to recognize important weather features. For both runs for the widespread precipitation cases and the MCS case, each velocity scan for each case was scored based on the errors that were visually seen. The scoring scheme, adapted from Witt, 2007, starts with 100 points. Points were deducted for the size and location of errors. The following table provides the guidelines used in the scoring:

Description of error	Penalty
Very Small Patch	-1 to -4
Small Patch	-4 to -8
Large Patch	-8 to -12
Swath of ~20 degrees short	-12 to -16
Swath of ~20 degrees long	-16 to -20
Swath of ~40 degrees short	-20 to – 24
Swath of ~40 degrees long	-24 to -28
Swath of ~60 degrees short	-28 to -32
Swath of ~60 degrees long	-32 to -38

Swath of ~90 degrees	-38 to -44
Swath of ~120 degrees	-44 to -50

Errors were also weighted based on their location. If the error was located in an important feature of the velocity field, the points deducted were doubled. The score of each scan was then averaged with the other scores of the data case to produce an average score for the case at each elevation. The two elevation averages were then averaged to produce an overall score.

5. RESULTS

5.1 *Widespread Precipitation Cases*

Areal time trends of all four widespread precipitation cases showed no operationally significant decrease either in velocity data or increase in range folded data. For the October 10, 2006 case, the 3-Scan version provided an average of 98.08 percent of the echo coverage as velocity data while the 2-Scan version provided an average of 97.75 percent (Table 1), a decrease of 0.33 percent. For the October 15-16, 2006 case, the 3-Scan version provided an average of 98.89 percent of the echo coverage as velocity data while the 2-Scan provided 98.79 percent, a decrease of 0.10 percent. For the November 5-6, 2006 case, the 3-Scan provided an average of 97.97 percent of the echo coverage as velocity data while the 2-Scan version provided 97.66 percent, a decrease of 0.31 percent. For the fourth case on December 29-30, 2006, the 3-Scan version provided an average of 98.42 percent of the echo coverage as velocity data and the 2-Scan version provided 98.26 percent, a decrease of 0.16 percent. The average of these four widespread precipitation cases indicates the 3-Scan version provided velocity data for 98.34 percent of echo coverage while the 2-Scan version provided 98.11 percent, a decrease of 0.23 percent. Table 2 shows the outlier frequencies for these four cases. Note the 2-Scan version had a substantial decrease in the percent of outliers for the 5 m s^{-1} category and a smaller decrease for the 10 m s^{-1} category compared to the 3-Scan version. For categories above 10 m s^{-1} the frequency of outliers was about the same or marginally higher for the 2-Scan version. The number of outliers in these categories is extremely small. For dealiasing errors (Table 3), the 2-Scan version scored 99.67 out of 100 while the 3-Scan version scored 99.61 out of 100. The 2-Scan version had fewer dealiasing errors than the 3-Scan version.

5.2 *Mesoscale Convective System*

The Mesoscale Convective System (MCS) on June 19-20, 2007 was the strongest case analyzed in terms of severe weather with large hail and strong winds reported in central Oklahoma in the Storm Prediction Center's Storm Reports. As with the widespread precipitation cases, areal time trends show the 2-Scan Enhanced version had nearly the same volume of velocity as the 3-Scan version. It should be noted that, although close, a larger volume of velocity was lost than in the previous cases. Still, we consider the loss as not operationally significant. Overall for the MCS, the 3-Scan version was able to provide an average of 96.35 percent of the echo coverage as velocity data while the 2-Scan version provided 95.87 percent, a decrease of 0.48 percent. Again, Table 2 shows the results of the outlier analysis. As with the previous four cases, 2-Scan version has a lower frequency of outliers than the 3-Scan version for the 5 m s^{-1} category. For the other categories, the frequency of outliers was slightly higher. In terms of dealiasing errors the 2-Scan version scored 96.19 out of 100 while the 3-Scan version scored 97.83 out of 100. This shows an increase in velocity dealiasing errors for the MCS for the 2-Scan version. The velocity dealiasing errors with the 2-Scan version mostly occurred during one specific period which was in the area of inflow/outflow boundary as it passed through the beginning of second trip for the SZ-2 (PRF 8 scan) about 117 km southeast of the radar. At this distance, the SZ-2 scan had range-folded data. The 2-Scan version of VCP 121 has only the PRF 4 scan to provide velocity data while the 3-Scan version has both the PRF 4 and PRF 6 scans to use with dealiasing.

5.3 *Tropical Storm Erin*

Areal time trends for Tropical Storm Erin on August 18, 2006 showed that, as with the other cases, the area provided by the 2-Scan version was nearly identical to the 3-Scan version. The 3-Scan version was able to provide an average of 99.03 percent of the echo coverage as velocity data while the 2-Scan version was able to provide 98.87 percent of the total field, a decrease of 0.16 percent. Table 2 shows the frequency of outliers for 2-Scan version was lower for all categories than the 3-Scan version. This case was not scored for dealiasing errors.

6. SUMMARY AND CONCLUSIONS

The data supports further testing of the 2-Scan Enhanced VCP 121. An average of the 6 cases shows only a 0.26 percent loss of velocity data using the 2-Scan version. Outlier frequencies averaged for the 6 cases indicates the 2-Scan version reduces the number of outliers for the two lowest categories (<=10 m s^{-1}) and increases only slightly the frequency of outliers for the higher categories (> 10 m s^{-1}). The decrease in outliers occurs because the 2-Scan enhanced VCP produces a smoother (cleaner) velocity field, which can be seen around the beginning of 2^{nd} trip upon careful examination. An average of the 5 cases for which velocity dealiasing was scored, shows the performance of the 2-Scan Enhanced VCP 121 decreased slightly by 0.27 percent. We believe a real-time 2-Scan Enhanced VCP 121 would perform better than the results shown in this study because there would not be fifteen second gaps between the first and third Doppler scans at the two lowest elevations. Overall, the results support moving forward with a field test of the 2-Scan Enhanced

VCP 121. In the future other VCPs that use SZ-2 could be modified to include an extra PRF 4 Doppler scan.

7. ACKNOWLEDGMENTS

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Figure 1. Reflectivity image of widespread precipitation case on December 30, 2006 at 01:12:37Z. The range rings are every 93 km (50 n mi). Beam blockage from a water tower is evident to the northeast in this and subsequent figures.

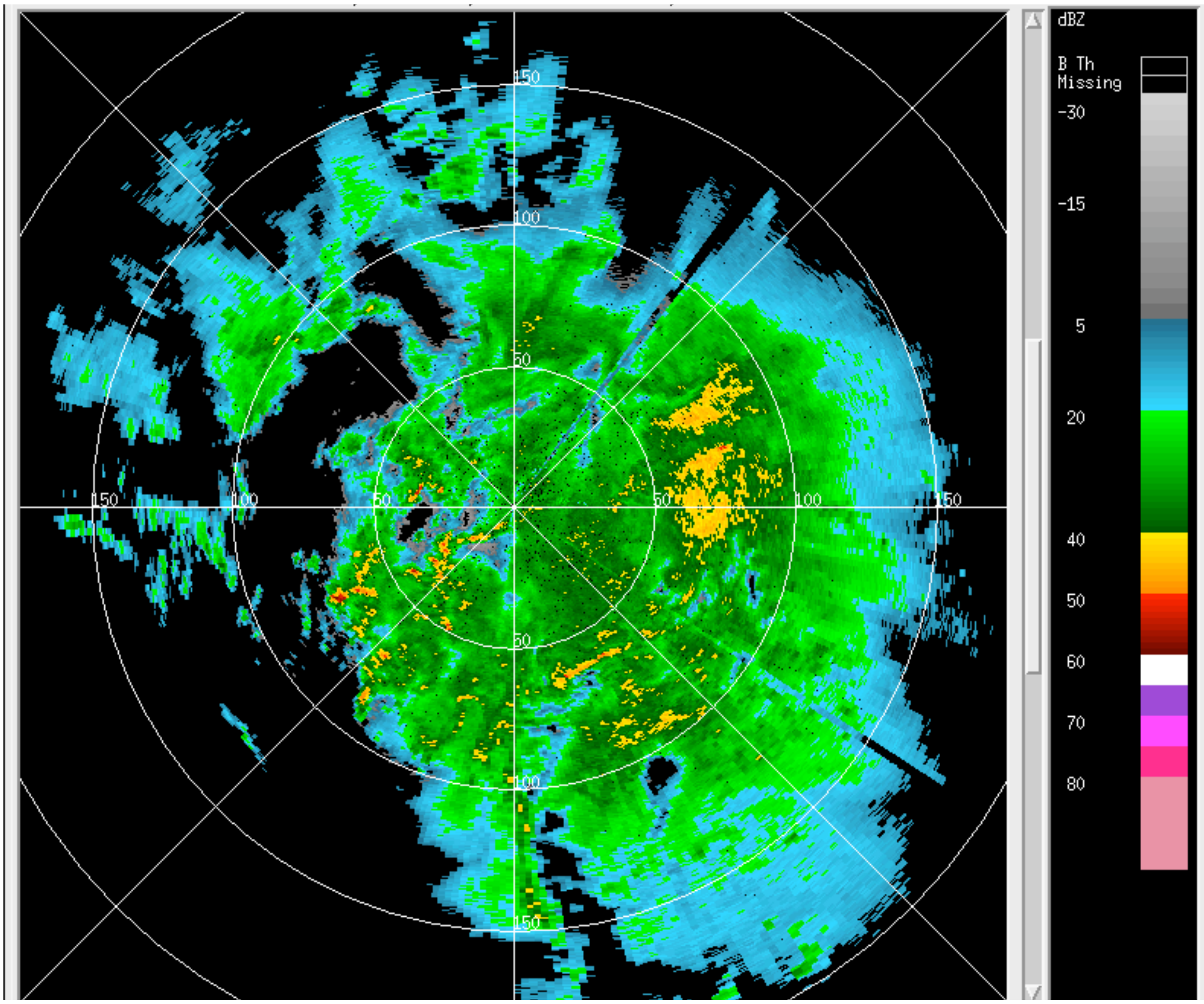

Figure 2. 3-Scan Enhanced VCP 121 velocity image from December 30, 2006 at 01:12:37Z. The reds indicate velocities away from the radar and green indicates velocities towards the radar. The range rings are every 93 km (50 n mi). Notice that there is very little range folded (purple) information on the image. Also note the strong inbound velocities of nearly 45 m s^{-1} about 213 km (115 n mi) range and 200 degrees azimuth.

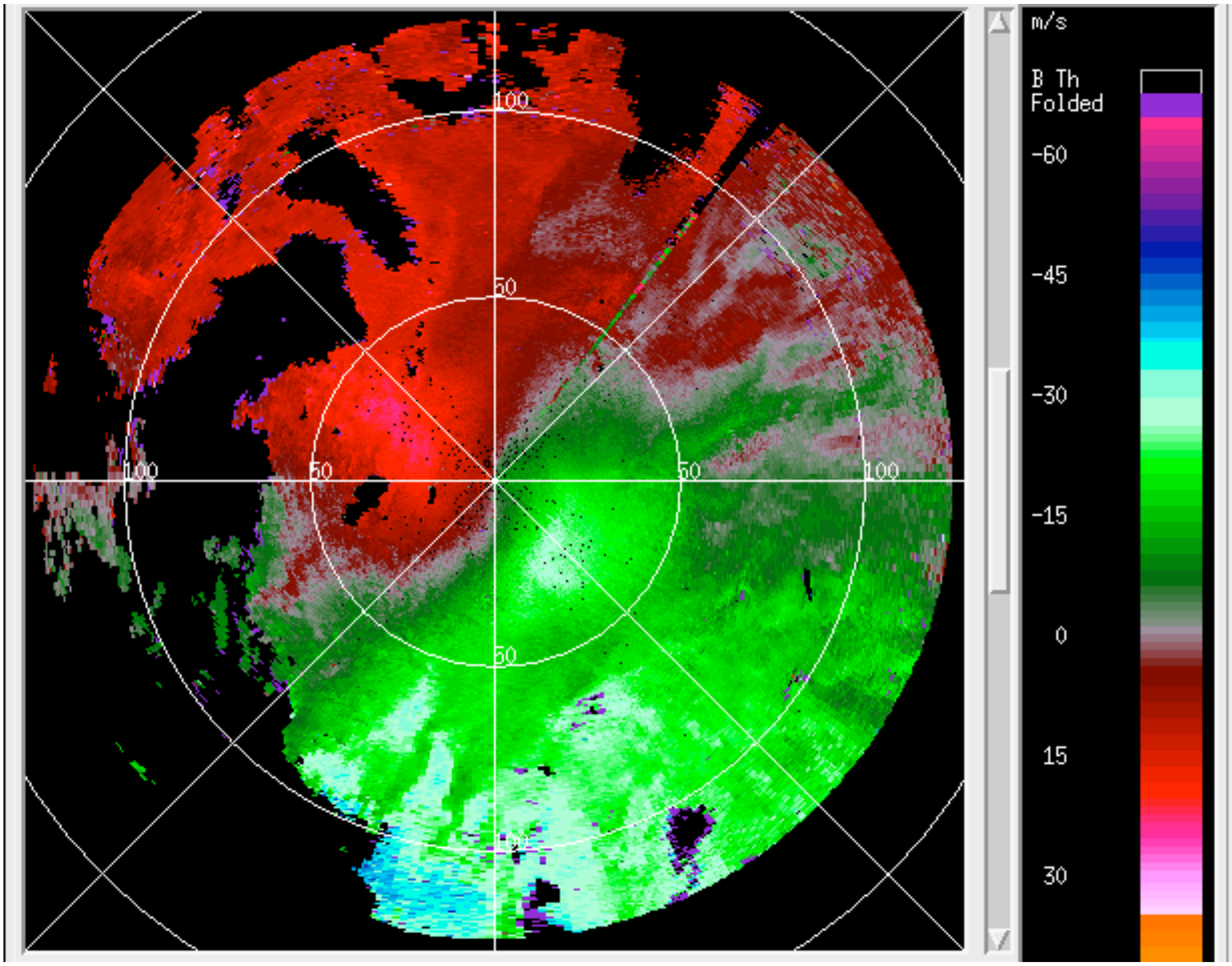

Figure 3. 2-Scan Enhanced VCP 121 velocity image. Notice that Figures 2 and 3 are virtually identical. Notice, also, that at around 139 km (75 n mi) the image is a little cleaner all the way around than Figure 2.

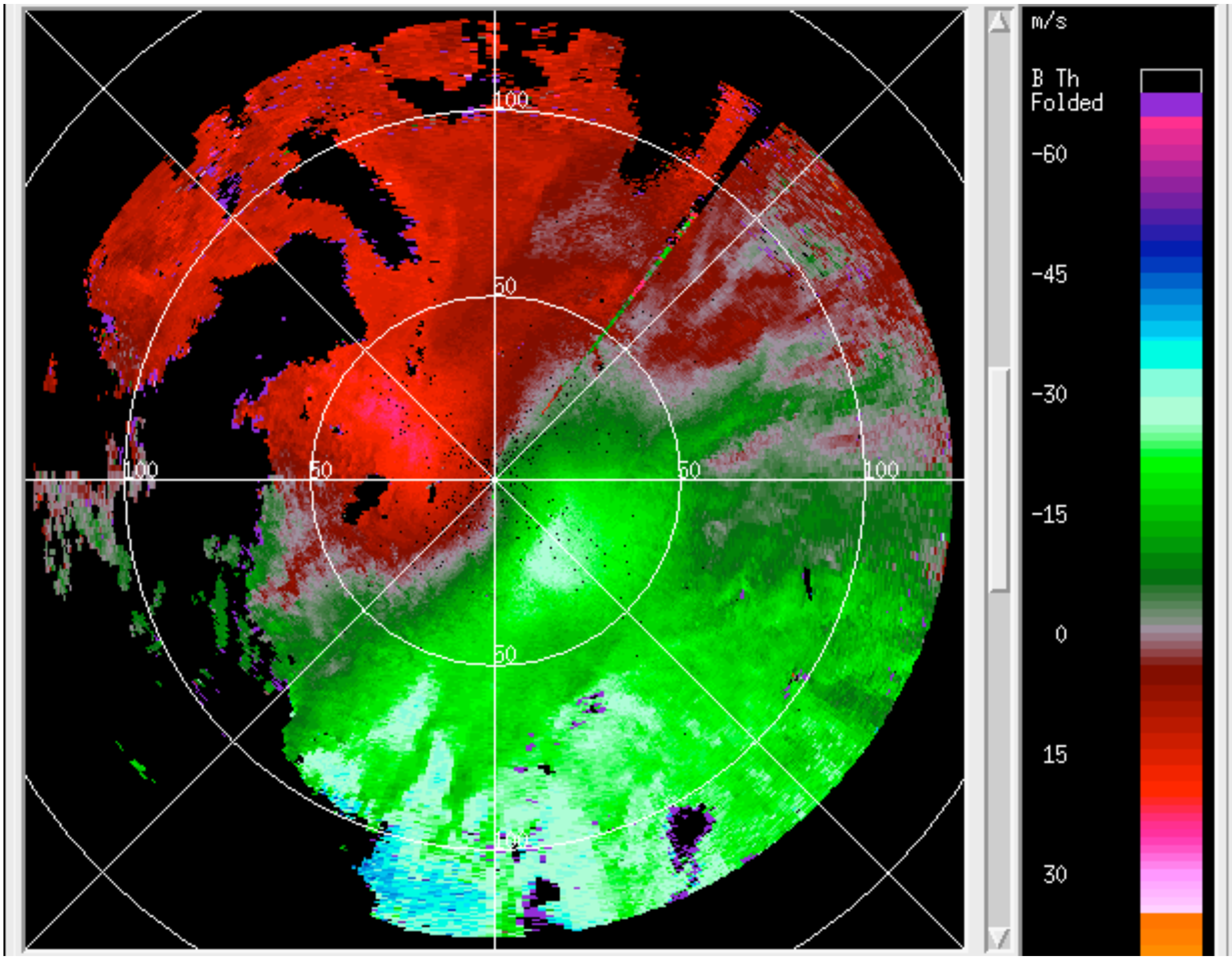

Figure 4. Reflectivity image from the mesoscale convective system on June 20, 2007 at 05:45:48Z. Notice that the storm has formed an outflow boundary.

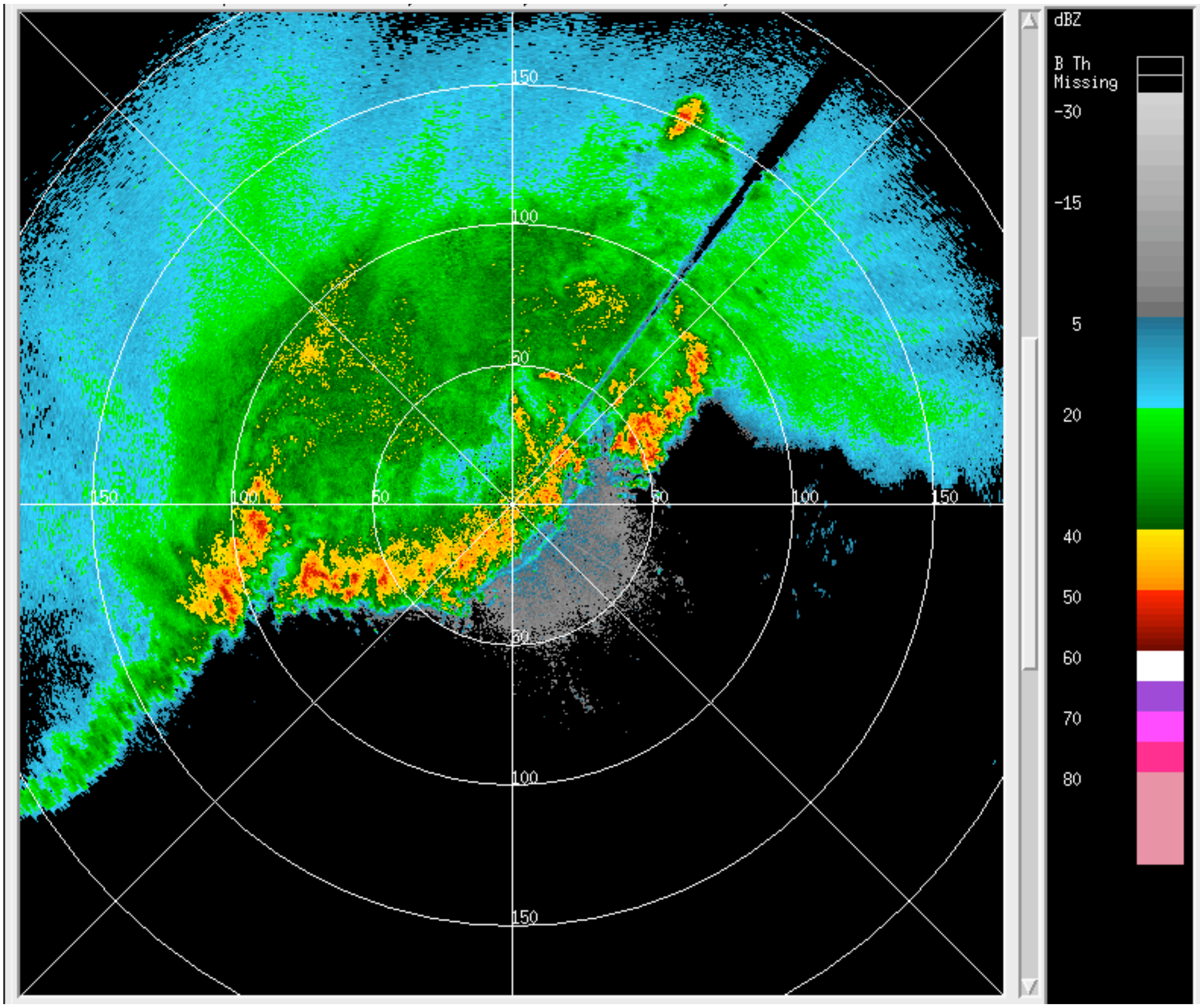

Figure 5. 3-Scan Enhanced VCP 121 velocity image from the mesoscale convective system on June 20, 2007 at 05:45:48Z from KCRI. Notice the strong outbound winds south of the radar.

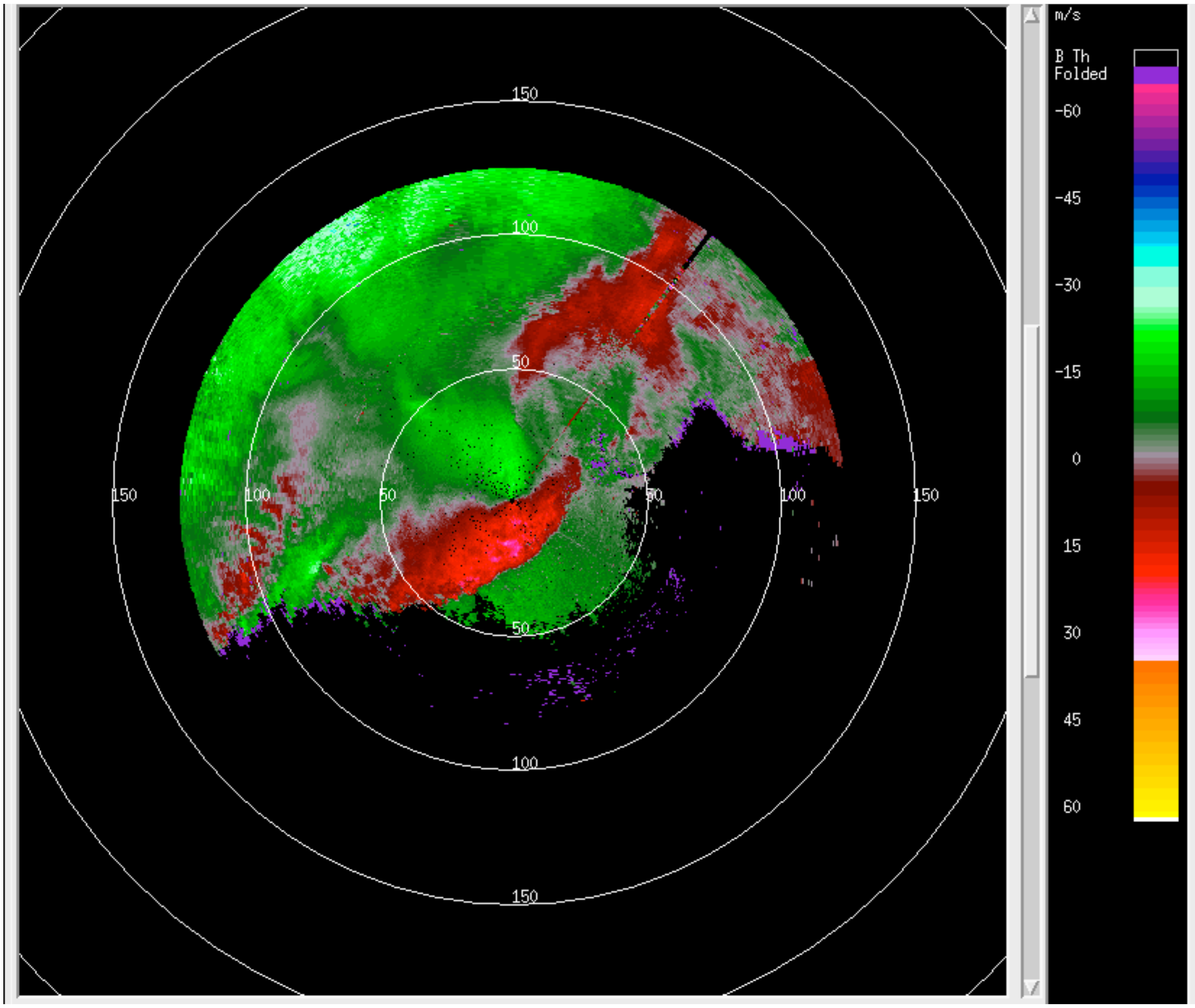

Figure 6. 2-Scan Enhanced VCP 121 velocity image from June 20, 2007 at 5:45:48Z from KCRI. Notice again the cleaner ring around 75 n mi when compared to Figure 5.

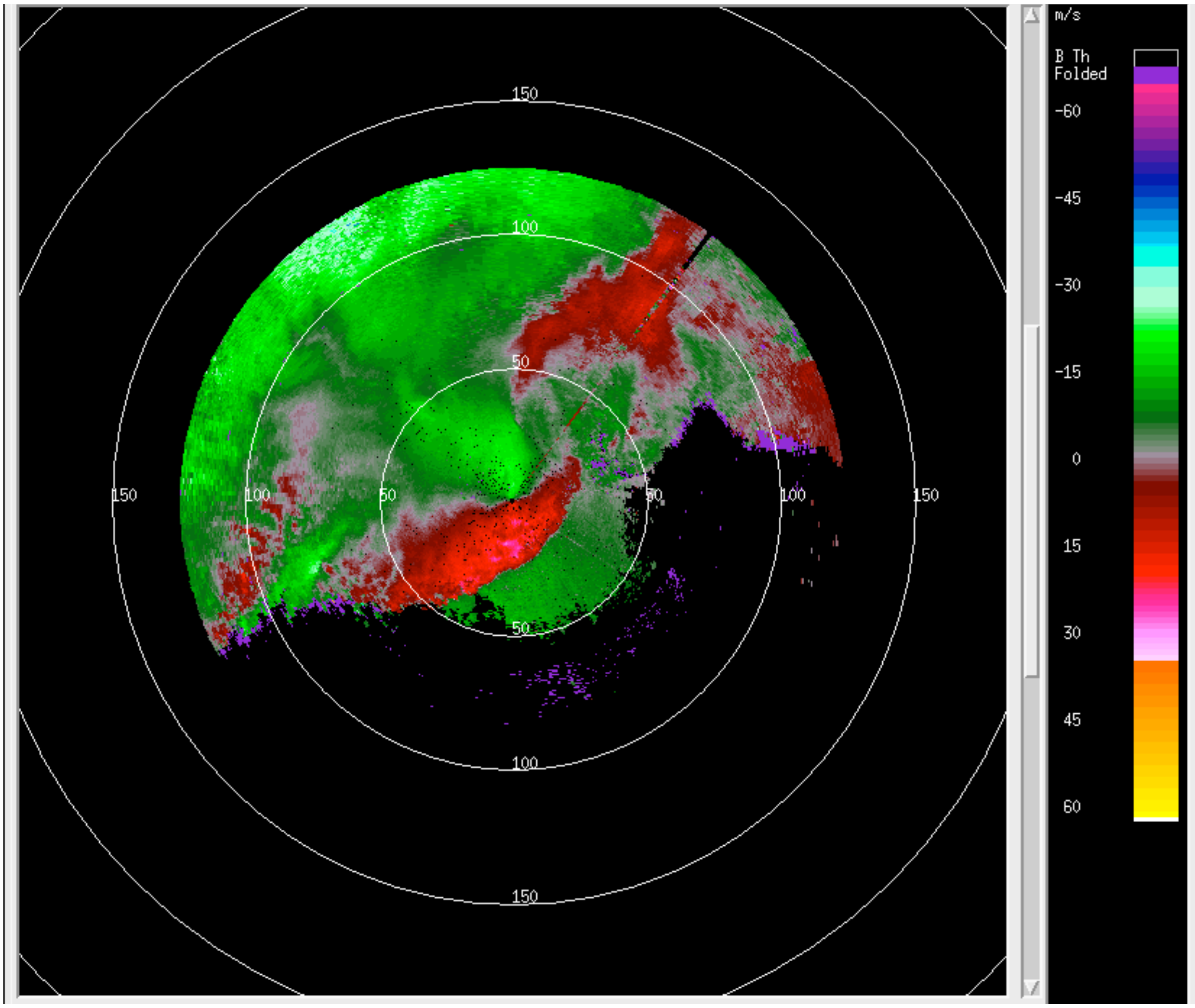

Table 1. Summary of the average percent of echo coverage that was velocity data for each case studied for the 3-Scan and 2-Scan version of the Enhanced VCP 121.

Case	No. of Hours	Percent Area 3-Scans	Percent Area 2-Scans	Weather Event
10 Oct 2006	6.2	98.08	97.75	Widepread Precipitation
15-16 Oct 2006	4.5	98.89	98.79	"
5-6 Nov 2006	8	97.97	97.66	"
29-30 Dec 2006	8	98.43	98.26	"
Average		**98.34**	**98.11**	
19-20 June 2007	13	96.35	95.87	Mesoscale Convective System
18 Aug 2007	8.5	99.03	98.88	Tropical Storm Erin
Overall Average		**98.13**	**97.87**	

Table 2. Summary of the average frequency of outliers, by percent, of the velocity fields for 6 outlier categories for each case and overall average. Note that for the 5 m s^{-1} category the 2-Scan version had fewer outliers for all cases.

		Percent Outlier Data											
		5 m/s		**10 m/s**		**15 m/s**		**20 m/s**		**25 m/s**		**30 m/s**	
Case	**No. of Hours**	**3-Scan**	**2-Scan**	**3-Scan**	**2-Scan**	**3-Scan**	**2-Scan**	**3-Scan**	**2-Scan**	**3-Scan**	**2-Scan**	**3-Scan**	**2-Scan**
10 Oct 2006	6.2	6.968	4.913	1.075	0.762	0.172	0.179	0.041	0.053	0.014	0.018	0.006	0.007
15-16 Oct 2006	4.5	1.607	1.392	0.248	0.226	0.061	0.063	0.021	0.023	0.010	0.010	0.004	0.004
5-6 Nov 2006	8	2.831	2.268	0.488	0.427	0.126	0.136	0.041	0.051	0.016	0.022	0.006	0.010
29-30 Dec 2006	8	2.022	1.747	0.365	0.327	0.104	0.102	0.038	0.041	0.016	0.018	0.006	0.007
Average		**3.357**	**2.580**	**0.544**	**0.435**	**0.116**	**0.120**	**0.035**	**0.042**	**0.014**	**0.017**	**0.005**	**0.007**
19-20 June 2007	13	2.152	1.744	0.366	0.385	0.129	0.182	0.064	0.099	0.028	0.045	0.012	0.020
18 Aug 2007	8.5	1.071	0.878	0.261	0.189	0.113	0.091	0.059	0.048	0.031	0.024	0.019	0.011
Overall Average		**2.775**	**2.157**	**0.467**	**0.386**	**0.118**	**0.125**	**0.044**	**0.053**	**0.019**	**0.023**	**0.009**	**0.010**

Table 3. Summary of the average dealiasing error scores for each data case and the overall average. A higher score indicates fewer velocity dealiasing errors.

Case	No. of Hours	Dealiasing Error Scores 3-Scans	Dealiasing Error Scores 2-Scans	Weather Event
10 Oct 2006	6.2	99.697	99.693	Widepread Precipitation
15-16 Oct 2006	4.5	99.430	99.610	"
5-6 Nov 2006	8	99.850	99.822	"
29-30 Dec 2006	8	99.465	99.565	"
Average		**99.610**	**99.673**	
19-20 June 2007	13	97.830	96.189	Mesoscale Convective System
18 Aug 2007	8.5	N/A	N/A	Tropical Storm Erin
Overall Average		**99.254**	**98.976**	