Concept of Operations for the Enhanced VCP 121 to Mitigate Range Aliasing

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1. Introduction

This document describes the changes to the volume coverage pattern VCP 121 for Build 10. The most significant change is the inclusion of the Sachidananda-Zrnić (SZ-2) algorithm for mitigating range folding. The use of SZ-2 in VCP 121 is expected to provide up to 98 percent of coverage out to 125 n mi (230 km) for weather events with extensive signal.

1.1 Multiple PRF Dealiasing Algorithm (MPDA)

VCP 121, the first VCP specifically designed to reduce range folding, is the coverage pattern that is required by the Multiple Pulse Repetition Frequency (PRF) Dealiasing Algorithm (MPDA). It was fielded in the spring of 2004 in Build 6. The MPDA mitigates range folding by combining Doppler data from up to three cuts at the same elevation angle but where each cut uses a different PRF. Changing the PRF changes the unambiguous range and thus the areas that may be shown as range folded. The primary PRFs used are 1282, 1095, and 857 Hz with unambiguous ranges of 64 n mi (117 km), 75 n mi (137 km), and 95 n mi (175 km), respectively. In the RPG human computer interface (hci), these may be displayed as PRF numbers 8, 6, and 4, respectively. Experience has shown the MPDA works well out to about 95 n mi (175 km) but is inconsistent in reducing range folding beyond this range.

Another feature of the MPDA is its approach to velocity dealiasing. It takes advantage of having up to three independent measurements of velocity for the same point in space. This can improve reliability of velocity dealiasing. However, a region with only measurements from PRF number 4 may have velocity dealiasing errors because its corresponding Nyquist velocity is only about 22 m s^{-1}. The MPDA runs on the 0.5, 1.45, 2.4, 3.35 and 4.3 degree lowest elevation angles.

1.2 Sachidananda/Zrnić Algorithm (SZ-2)

In Build 9 three new volume coverage patterns, VCP 211, 212, and 221 were fielded that use the Sachidananda-Zrnic (SZ-2) algorithm to mitigate range folding. The SZ-2 algorithm separates weak from strong trip echo by varying the phase of multiple consecutive pulses. SZ-2, a modified version of the Sachidananda/Zrnić SZ (8/64) algorithm, is used to mitigate range folding commonly referred to as “purple haze” in conjunction with a high PRF number such as 8 (~1300 Hz, unambiguous range of 64 n mi, and Nyquist velocity of ~34 m s^{-1}) to mitigate velocity dealiasing errors. To separate

out the first trip from the second trip echo, SZ-2 uses a sequence of eight modulation phases to change the transmitted phase of each succeeding radar pulse. By changing the phase of succeeding pulses SZ-2 can separate first trip from second trip echo. Sixty-four pulses are used to reduce variance of the estimate. Because of the possibility of signal contribution from third and fourth trip echo when using high PRFs, the original SZ (8/64) algorithm was modified to use a surveillance scan to assign energy to the appropriate trip, hence the designation SZ-2. Use of a surveillance scan follows the same pattern as the WSR-88D VCPs' split cuts. The SZ-2 processing is only applied on the split cuts (elevation angles less than 1.65 degrees). As discussed in the limitations section of the Concept of Operations for the SZ-2 Range-folding Mitigation Technique (provided with Build 9) each of these VCPs is limited to using only one PRF at the elevation angles where SZ-2 is used. VCP 211 uses PRF number 8, VCP 212 uses PRF number 6, and VCP 221 uses PRF number 5. This algorithm works well at far ranges but leaves a band of range folded signal at the start of the second trip. Finally, while significantly mitigating range aliasing, SZ-2 still requires an algorithm at the RPG to do velocity dealiasing

1.3 Combining SZ-2 and MPDA for VCP 121

The two techniques are readily combined. The SZ-2 algorithm runs in the SIGMET RVP8 processor which is part of the RDA system while the MPDA runs in the Radar Product Generator (RPG) Linux work station. Thus the SZ-2 algorithm runs independently and sequentially before its hands velocity data to the MPDA. Because the MPDA requires PRF number 8 for the first Doppler cut, we use the same scan time and waveform specifications as for VCP 211 which also uses PRF number 8 (compare Figures 1a-c). The column that lists the waveform types now shows CS/SZ2 and CD/SZ2 rather than just CS and CD for the surveillance and first Doppler cut.

Another change to VCP 121 is the waveform specified for the second and third Doppler cuts at 0.5 and 1.45 degrees (split cuts). Instead of showing CD/WO they now show CD/W, the difference being that CD/WO is a contiguous Doppler cut without range unfolding at the RDA while CD/W is a contiguous Doppler cut with range unfolding done at the RDA. (Because the legacy RDA could not range unfold extra Doppler cuts at the same elevation angle, the MPDA did range unfolding in the RPG. The ORDA now does range unfolding of sequential Doppler cuts for the lowest two elevation angles). This change is required because the algorithm to recombine super resolution data into baseline resolution data required for the meteorological algorithms runs in the RPG before velocity dealiasing is done.

2 Examples

Data sets collected on the Radar Operation Center's (ROC) test bed WSR-88D (KCRI) over the past year and from field sites during the latter half of CY 2007 have shown the combination of the SZ-2 algorithm and the MPDA in VCP 121 significantly mitigates residual range aliasing left by each technique

2.1 Winter Storm Case

Between December 29 and 31, 2006 a major winter storm dumped up to 18 inches of snow in the Oklahoma Panhandle and up to four inches of rain in southeastern Oklahoma. During this period the ROC WSR-88D collected Level 2 Archive data using the enhanced VCP 121. For several hours on December 29-30, 2006 the Norman forecast office collected similar data using the baseline VCP 121 on its WSR-88D (KTLX) located about 10 n mi (18 km) east-northeast of the ROC's radar. Figure 2a shows a side-by-side comparison of reflectivity products from KCRI and KTLX collected about 02Z on December 30th. The overall patterns match quite well. Minor differences would be expected due to differences in beam propagation. Figure 2b shows a side-by-side comparison of the corresponding velocity products. The velocity product from KTLX shows extensive range folding beyond 95 n mi (175 km) while the velocity product from KCRI has almost no range folding. Figure 2c simulates the velocity product that would be obtained if only the first, SZ-2 Doppler cut were processed. This is the velocity image that the use of VCP 211 would have generated. A band of range folding is clearly seen at the start of second trip about 64 n mi (117 km).

2.2 Tropical Cyclone Case

On September 12, 2007 Tropical Storm Humberto formed about 83 n mi (154 km) south-southwest of Galveston, TX. It intensified as it first moved northward and then turned to the north-northeast. On September 13th it became a hurricane just off the Texas coast near High Island and made landfall about 07Z at its peak intensity with winds about 85 mph. Figure 3a shows a side-by-side comparison of reflectivity products from the Houston, TX WSR-88D (KHGX) and the Lake Charles, LA WSR-88D (KLCH) about 07Z. At this time the eye was about 43 n mi (80 km) east-northeast of KHGX and about 65 n mi (120 km) west-southwest of KLCH. KHGX was operating with the baseline VCP 121 while KLCH was operating with the enhanced VCP 121. Although the images match well, KHGX is already starting to overshoot outer bands east of the eye. Figure 3b shows side-by-side velocity products from KHGX and KLCH. Note that the KHGX velocities around the eye are partially obscured by range folded signal while the velocities in the KLCH image are free of range folded signal. As in the winter storm case, extensive range folding occurs beyond 95 n mi (175 km). Figure 3c shows what the KLCH velocity image would have looked like had the radar been operating in VCP 211. A band of range folded signal encircles the radar and obscures part of the eye structure. Other areas appear noisier than the enhanced VCP 121 in Figure 3b.

3. Operational Considerations

The enhanced VCP 121 is intended to reduce range folding, it is best suited for use with weather events with wide-spread coverage (e.g., tropical cyclones or mesoscale convective systems) or that have extensive length such as squall lines. It will also prove helpful when there are both enhanced clear-air returns near the radar after sunset and precipitation events away from the radar.

3.1 Volume Scan Update Rate

Because the SZ-2 processing requires 64 pulses (43 pulses are used in the baseline VCP 121), the antenna rotation rate is slightly slower for the first Doppler scan at both 0.5 and 1.45 degrees elevation. Also, the number of surveillance pulses has been increased from 15 to 17 to match the VCPs that use only SZ-2. The slower rotation rates add about fifteen seconds to the total volume scan time for the enhanced VCP 121 for an estimated completion time of 5 minutes 45 seconds.

3.2 Extended Coverage with Super Resolution

New to Build 10 is the extension of velocity coverage to 162 n mi (300 km) at elevation angles at or below 1.5 degrees with half degree azimuth resolution. Velocity data beyond 125 n mi (230 km), when the echo coverage area is extensive, may be better seen using SZ-2 VCPs 212 or 221 than the enhanced VCP 121 or VCP 211. To understand this, consider the number of trips for each PRF number lying within 162 n mi (300 km) as shown in row 4 of the table below. VCP 221, which uses PRF number 5, has just two trips. VCP 212, which uses PRF number 6, has 2.2 trips whereas VCP 211 (and also VCP 121), which uses PRF number 8, has 2.6 trips. The fractional part that is higher than 2 represents third trip data. When a high PRF is used, the possibility of signal from the third or fourth trip increases. SZ-2 is capable of retrieving signal from the two strongest trips but if that signal is in the first two trips, data from the third trip will be displayed as range folded. Although VCP 121 uses Doppler cuts with PRF numbers 6 and 4, those cuts, not using SZ-2, only provide signal from the trip with the strongest return which, in most situations, is the first or second trip.

PRF Number	4	5	6	7	8
Range to end of 1st trip (n mi)	95	80	74	69	64
Range to end of 2nd Trip (n mi)	190	160	148	138	128
Trips within 162 n mi.	1.7	2.0	2.2	2.4	2.6
Trips within 248 n mi.	2.6	3.1	3.4	3.6	3.9

3.3 Adaptable Parameter Settings

Because of differences in range offsets between reflectivity and velocity data, a thin ring of velocities near the end of first trip/start of second trip that doesn't fit the adjacent velocity data may occur. This ring of "noisy" velocities can be removed via the adaptable parameters, Threshold (Fix Trip Minimum Bin) and Threshold (Fix Trip Maximum Bin). For fielding purposes for Build 10, the default value for Threshold (Fix Trip Minimum bin) is set to -3 and the value for Threshold (Fix Trip Maximum Bin) is set to +6 (Figure 4.) Attachment 1 describes testing done to arrive at these values. However, the Threshold (Fix Trip Minimum Bin) may be more optimally set with a value of +2. Sites are strongly encouraged to try using a value of +2.

3.4 Residual Range Folding

Despite its superior performance in removing range folding, the enhanced VCP 121 does not completely eliminate it. The major source of residual range folding occurs when the strongest echo lies in the third or fourth trips and there is also echo in the first and/or second trip. When that happens, the weaker signals in the first and second trip will be displayed as range-folded.

3.5 PRFs Cannot Be Changed

As with the baseline VCP 121, the RPG software does not allow an operator to change PRFs for the enhanced VCP 121.

3.6 Clutter Filtering

Like VCPs 211, 212, and 221, the enhanced VCP 121 also uses the SZ-2 algorithm. Therefore, operators should avoid using "All Bins" clutter filtering to remove anomalous propagation (AP) and should use clutter censor zones with care. When clutter is identified as being in bins at multiples of the unambiguous range, the SZ-2 algorithm will invoke a simple clutter to signal ratio test. This simple test may not remove all velocity and spectrum width data associated with AP. Reflectivity will, however, continue to be filtered correctly. For a more complete discussion please refer to the document "Concept of Operations For the SZ-2 Range-folding Mitigation Technique" provided with the Build 9 software kit. An advanced technique to recognize and remove clutter at the RDA is expected to be deployed in Build 11 that would eliminate most AP without requiring use of "All Bins" clutter filtering.

3.7 Spectrum Width Estimates

The MPDA stores both velocity and spectrum width estimates from each of the Doppler scans. After choosing a velocity from one of the three Doppler scans for the output velocity field, the MPDA selects the corresponding spectrum width value from the same Doppler scan for the output spectrum width field. Most of the velocity data for the combined SZ-2/MPDA are provided by the SZ-2 Doppler scan. Hence, most of the spectrum width estimates are provided by that scan as well.

Recall from the "Concept of Operations For the SZ-2 Range-folding Mitigation Technique" document the variance of the spectrum width estimates from weak trip echo is unacceptably high. Instead SZ-2 computes the spectrum width from the surveillance scan. Because of the low PRF used for the surveillance scan (the Nyquist velocity is about 11 m s^{-1} or 22 kt) the effective maximum meaningful value for the spectrum width is about 6 m/s in weak trip echoes. By design, if the computed spectrum width in weak trip exceeds 6 m s^{-1} (12 kt) for a particular bin, the bin is indicated as range folded. The consequence of this limitation is that there may be slightly more bins indicated as range folded for spectrum width data than for velocity data.

3.8 Increased Variance of Doppler Moments

For each bin, windowing is performed on the time series data depending on the combination of clutter and weather signal present. Where clutter is present a Blackman window is used, where range-overlaid weather signal occurs a Von Hann window is used, and where only weather signal occurs a Hamming window is used. The last is defined as the "default" ORDA window. Use of the windows increases the variance of the estimates for both velocity and spectrum widths. The Blackman filter, being the strongest, increases the variance by 50 percent, the Von Hann and Hamming windows increases variance by about 35 percent. (The default window may be changed to rectangular filtering in the future which doesn't increase the variance.) Clutter filtering that occurs in multiple trips is discussed under limitations.

3.9 Bibliography

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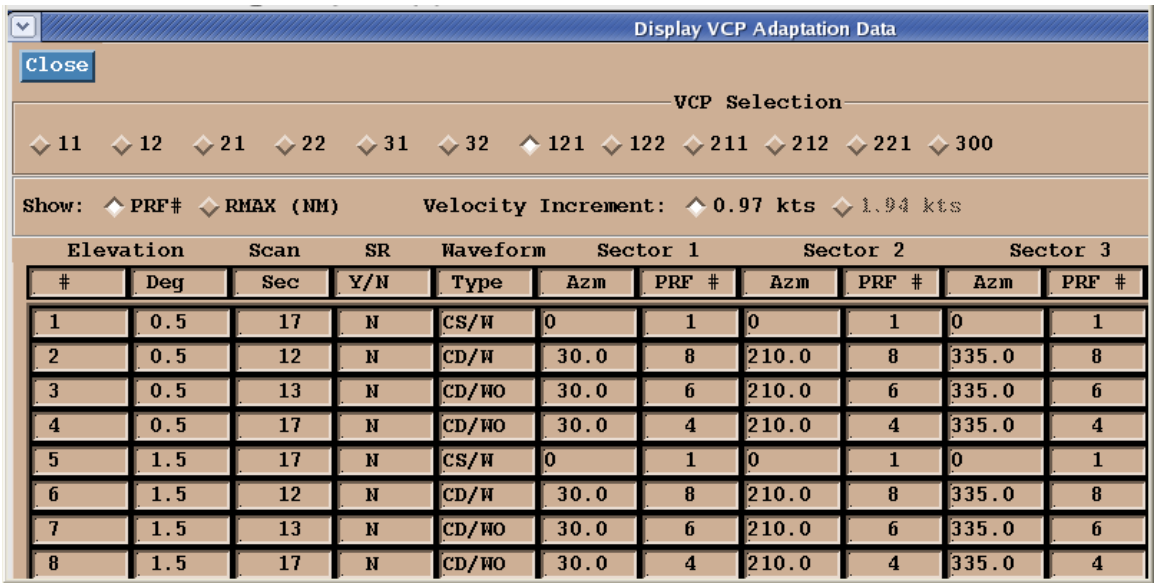
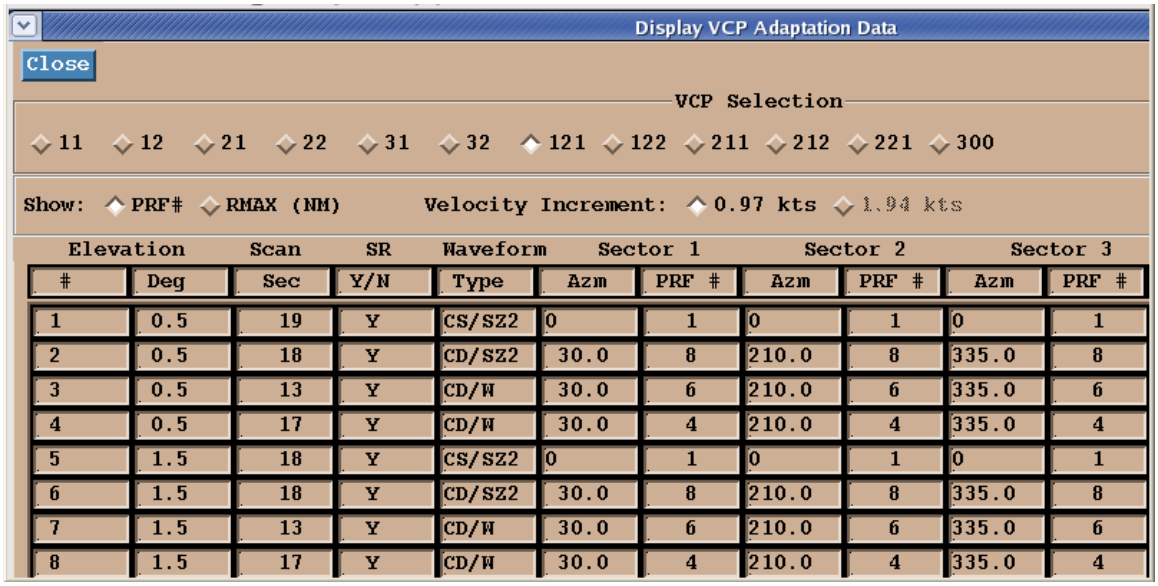


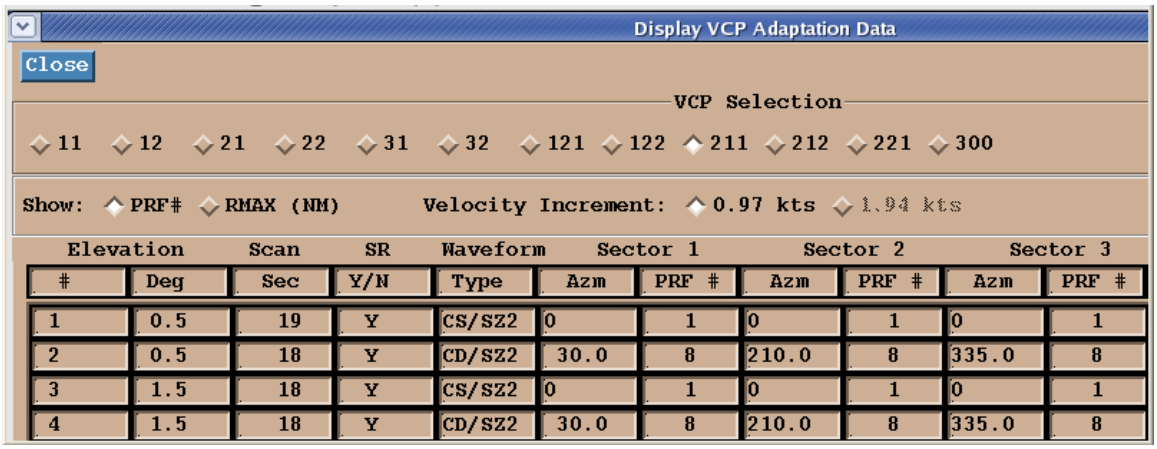
Elevation		Scan	SR	Waveform	Sector 1		Sector 2		Sector 3	
#	Deg	Sec	Y/N	Type	Azm	PRF #	Azm	PRF #	Azm	PRF #
1	0.5	17	N	CS/W	0	1	0	1	0	1
2	0.5	12	N	CD/W	30.0	8	210.0	8	335.0	8
3	0.5	13	N	CD/WO	30.0	6	210.0	6	335.0	6
4	0.5	17	N	CD/WO	30.0	4	210.0	4	335.0	4
5	1.5	17	N	CS/W	0	1	0	1	0	1
6	1.5	12	N	CD/W	30.0	8	210.0	8	335.0	8
7	1.5	13	N	CD/WO	30.0	6	210.0	6	335.0	6
8	1.5	17	N	CD/WO	30.0	4	210.0	4	335.0	4

Figure .1a Graphical user interface window (truncated) showing adaptation data for VCP 121 for Build 9. The waveform column for elevation cut numbers 3, 4, 7 and 8 show the Doppler data is not range unfolded at the RDA. VCPs 22 and 122 are test VCPs not fielded with operational rpg software.



Elevation		Scan	SR	Waveform	Sector 1		Sector 2		Sector 3	
#	Deg	Sec	Y/N	Type	Azm	PRF #	Azm	PRF #	Azm	PRF #
1	0.5	19	Y	CS/SZ2	0	1	0	1	0	1
2	0.5	18	Y	CD/SZ2	30.0	8	210.0	8	335.0	8
3	0.5	13	Y	CD/W	30.0	6	210.0	6	335.0	6
4	0.5	17	Y	CD/W	30.0	4	210.0	4	335.0	4
5	1.5	18	Y	CS/SZ2	0	1	0	1	0	1
6	1.5	18	Y	CD/SZ2	30.0	8	210.0	8	335.0	8
7	1.5	13	Y	CD/W	30.0	6	210.0	6	335.0	6
8	1.5	17	Y	CD/W	30.0	4	210.0	4	335.0	4

Figure 1b. Graphical user interface window (truncated) showing adaptation data for VCP 121 for Build 10. The waveform column for elevation cut numbers 1,2, 5, and 6 show that SZ-2 processing is invoked at the RDA. Elevation cut numbers 3, 4, 7 and 8 show the Doppler data is range unfolded at the RDA. VCPs 22 and 122 are test VCPs not fielded with RPG operational software.



Elevation		Scan	SR	Waveform	Sector 1		Sector 2		Sector 3	
#	Deg	Sec	Y/N	Type	Azm	PRF #	Azm	PRF #	Azm	PRF #
1	0.5	19	Y	CS/SZ2	0	1	0	1	0	1
2	0.5	18	Y	CD/SZ2	30.0	8	210.0	8	335.0	8
3	1.5	18	Y	CS/SZ2	0	1	0	1	0	1
4	1.5	18	Y	CD/SZ2	30.0	8	210.0	8	335.0	8

Figure 1c. Graphical user interface window (truncated) showing adaptation data for VCP 211 for Build 10. The waveform column for elevation cut numbers 1,2, 3, and 4 show that SZ-2 processing is invoked at the RDA. The time (sec) in the Scan column is the same as the time shown in Figure 1b rows 1, 2, 5 and 6, respectively. VCPs 22 and 122 are test VCPs not fielded with RPG operational software.

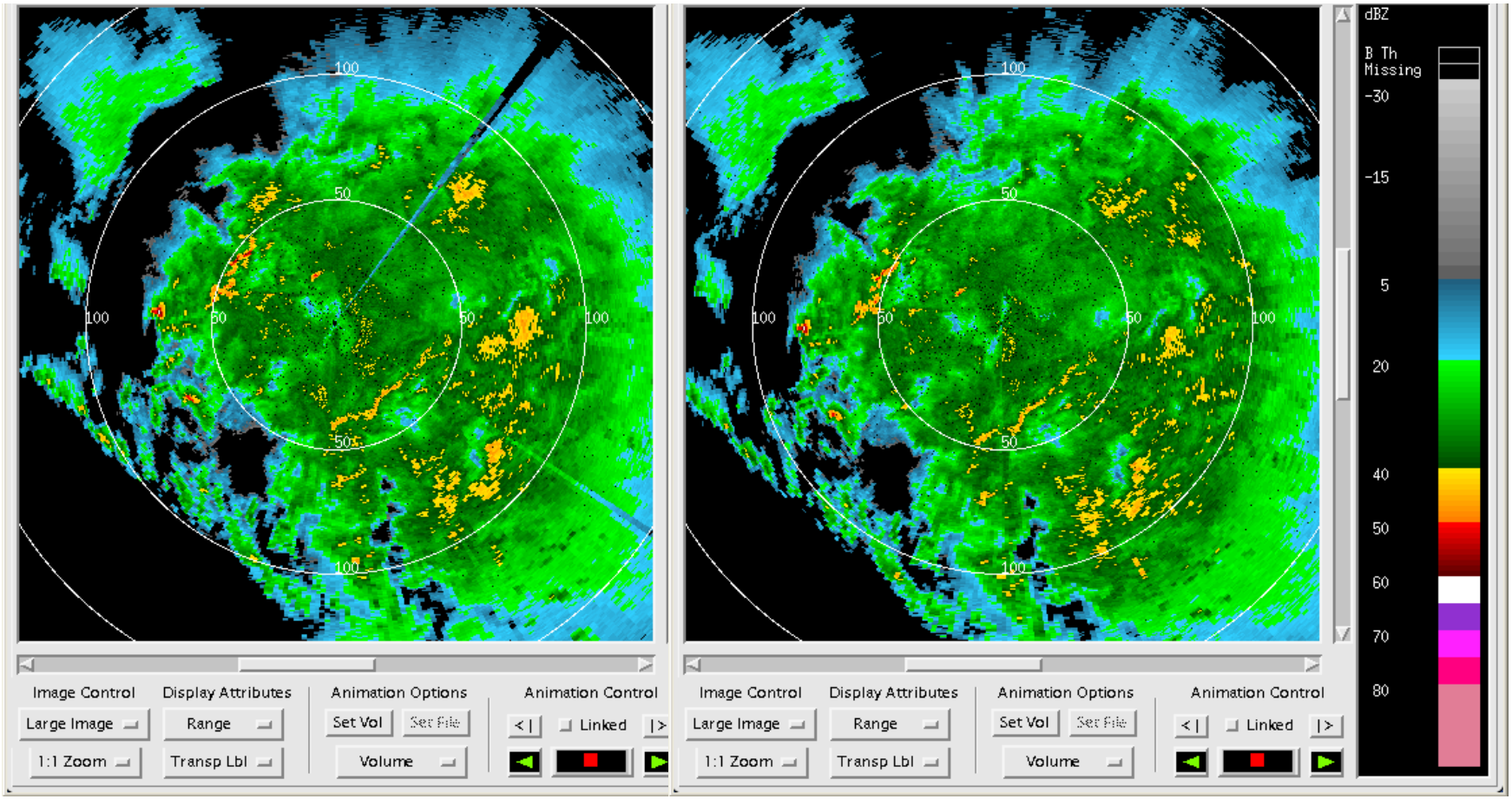


Figure 2a. Side by side comparison of reflectivity image from KCRI (left) and KTLX (right) for December 20, 2006 around 02Z. Beam blockage in the northeast and southeast quadrants due to towers is evident in the KCRI image. Coverage and overall intensity are similar. KTLX is located about 10 n mi east-northeast of KCRI. Range rings are every 50 n mi.

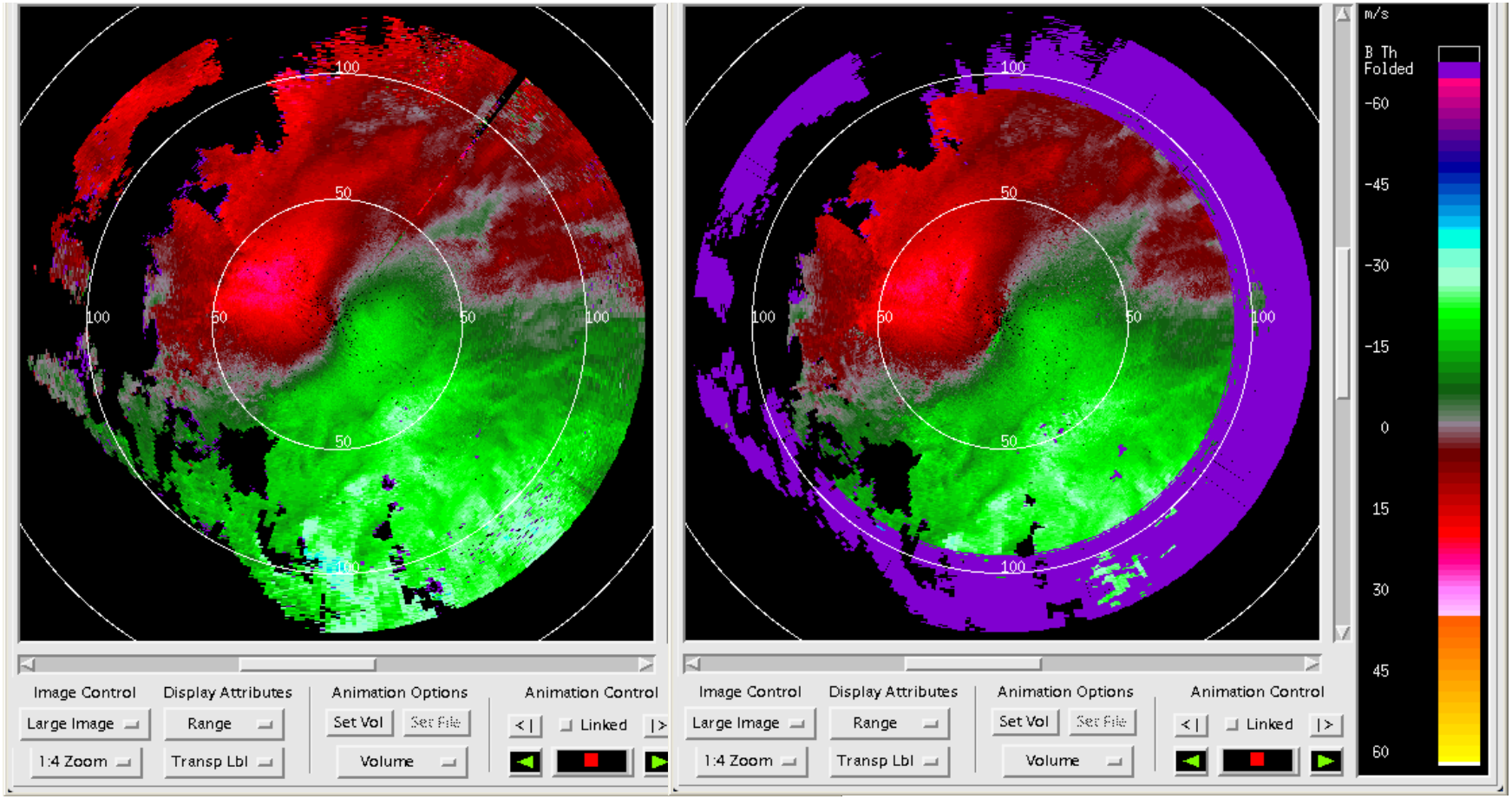


Figure 2b. Side by side velocity images for same date and time as in Figure 2a. KCRI on left is running with the enhanced VCP 121 and KTLX on right is running with the baseline VCP 121. Note for KTLX nearly all signal beyond 95 n mi is range folded. Range rings are every 50 n mi

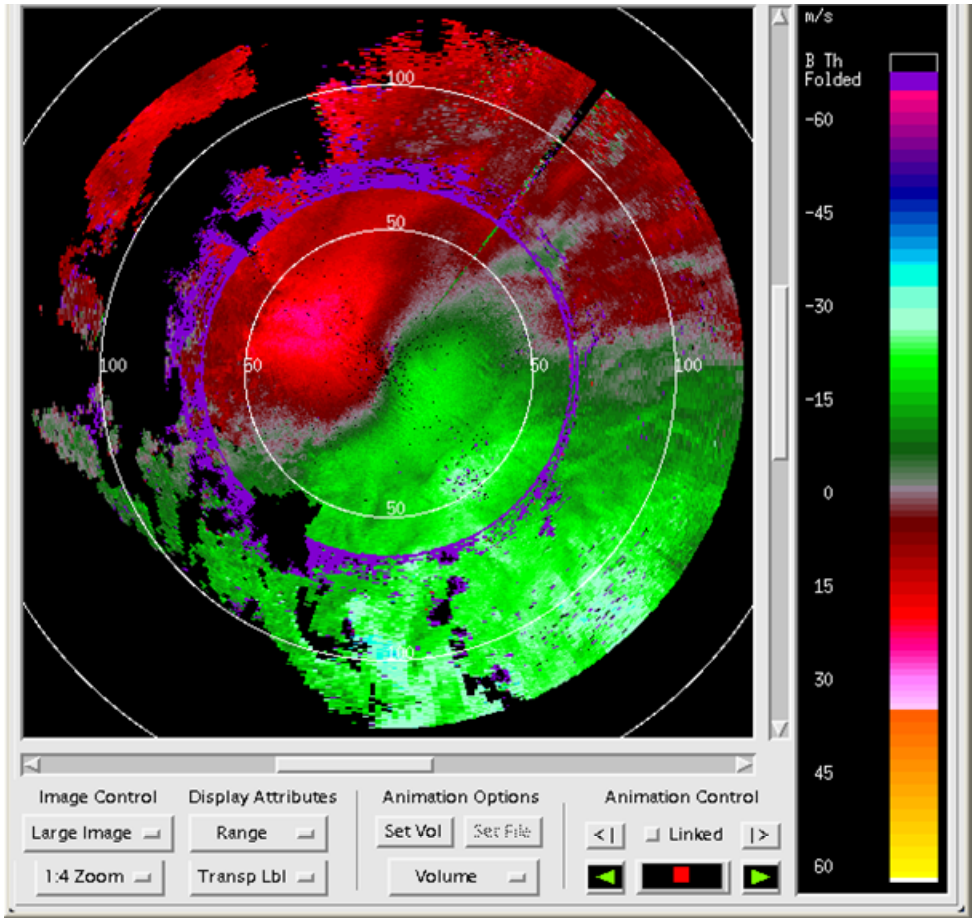


Figure 2c. KCRI Velocity image for same date and time as in Figure 2b. The 2nd and 3rd Doppler cuts were omitted thus simulating VCP 211. Note the band of range folding between 64 and 74 n mi. Range rings are every 50 n mi.

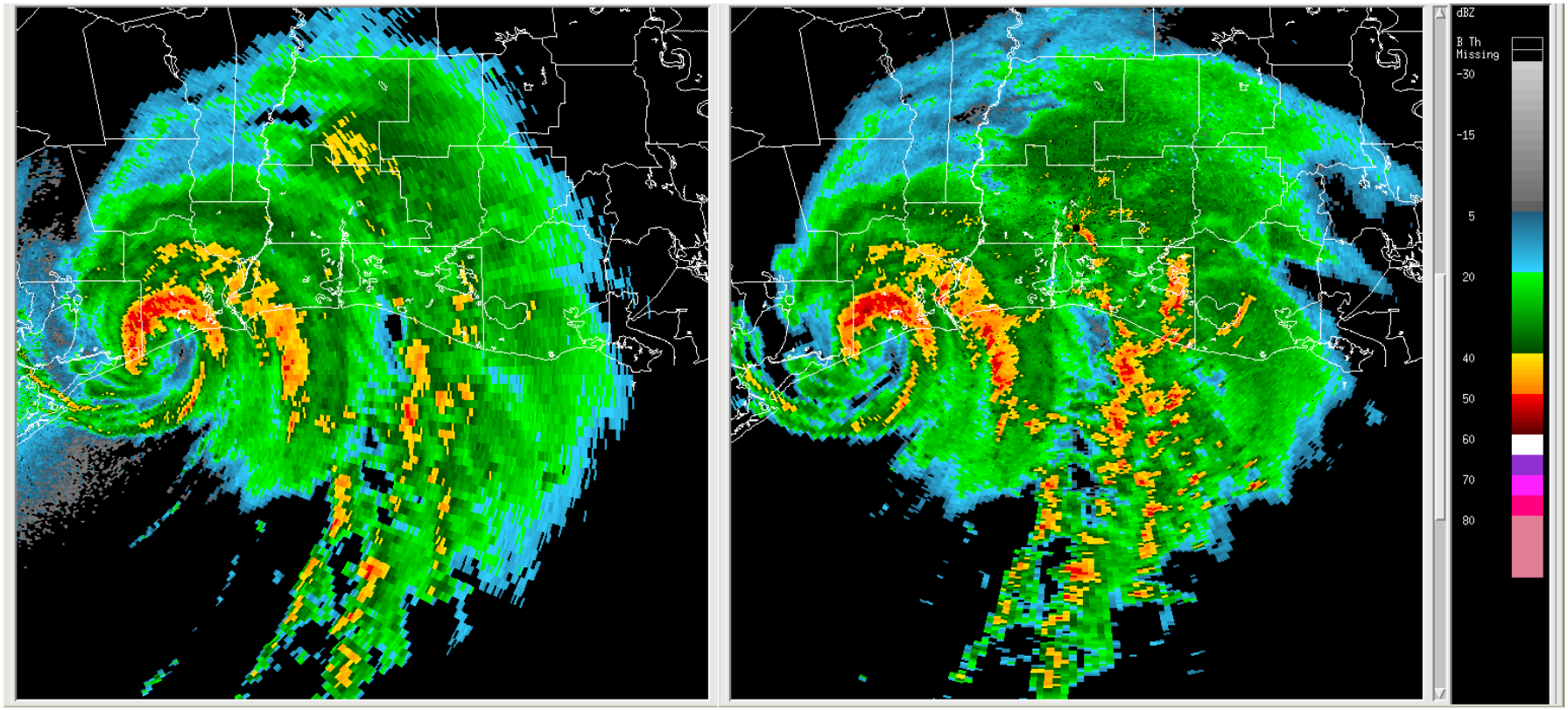


Figure 3a. Side by side comparison of reflectivity images from KHGX (left) and KLCH (right) for 07Z on September 13, 2007 about the time of Hurricane Humberto's peak intensity. Coverage and overall intensity are similar around the eye located left center in each image. KLCH is located about 110 n mi east-northeast of KHGX.

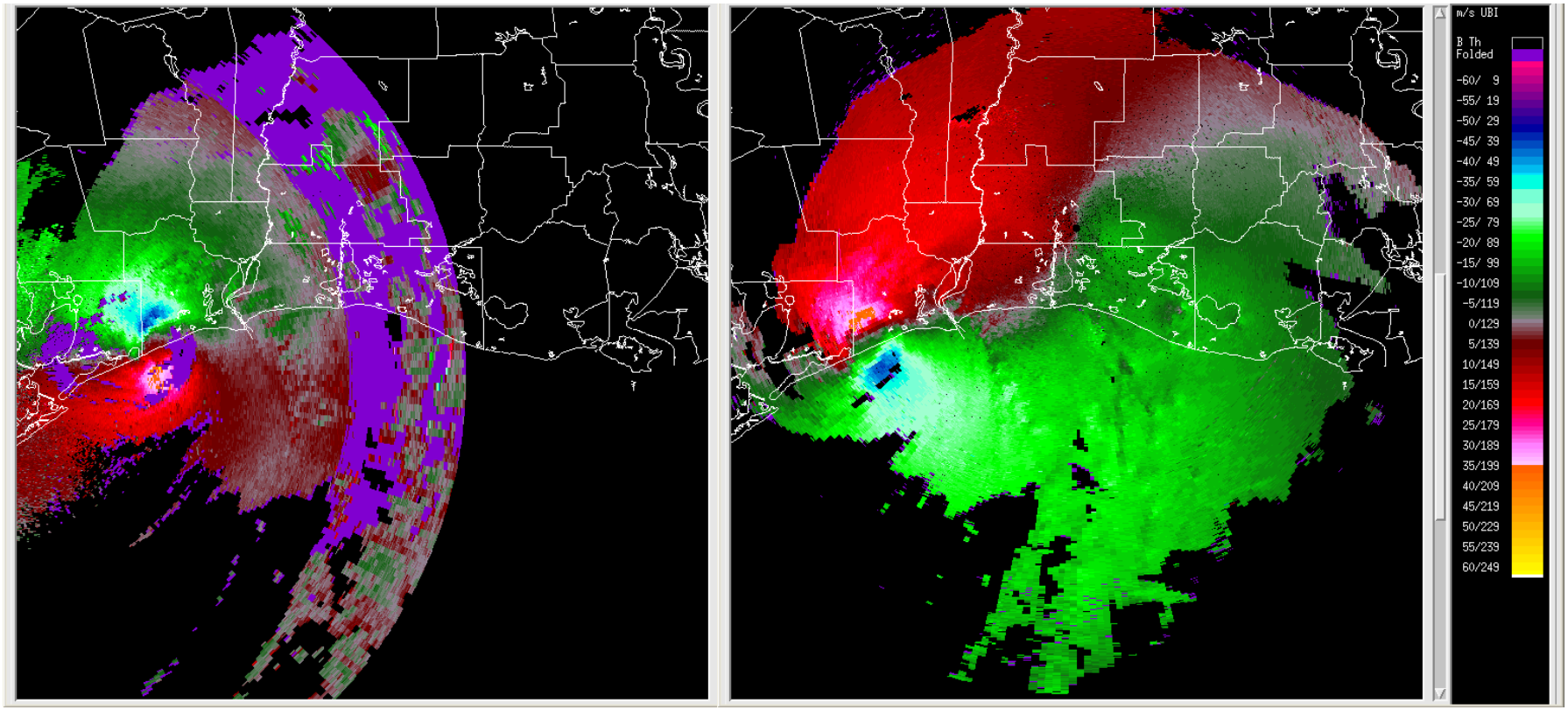


Figure 3b. Side by side comparison of velocity images from KHGX (left) and KLCH (right) for 07Z on September 13, 2007 about the time of Hurricane Humberto's peak intensity. KHGX is running the baseline VCP 121 and KLCH is running the enhanced VCP 121. Note the obstruction of the peak winds in the eye (left center in each image) due to range folding for KHGX. KLCH is located about 110 n mi east-northeast of KHGX.

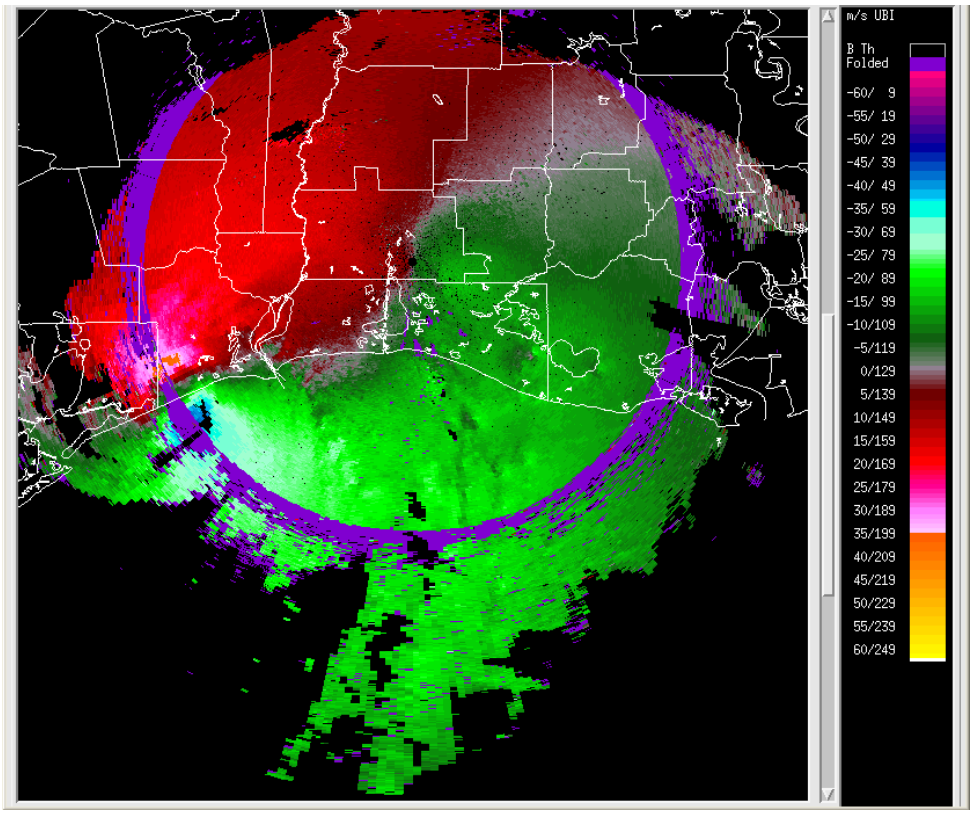


Figure 3c. KLCH Velocity image for same date and time as in Figure 3b. The 2nd and 3rd Doppler cuts were omitted thus simulating VCP 211. Note the band of range folding between 64 and 74 n mi that obstructs the peak winds in the eye left central.

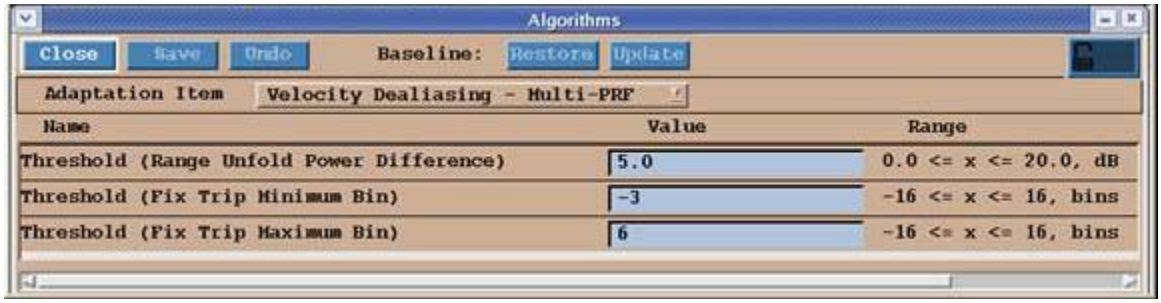


Figure 4. Graphical user interface screen showing the Build 10 default adaptable parameter values.

Attachment 1. Adjusting Adaptable Parameters for Build 10 for the Enhanced Multi-PRF Dealiasing Algorithm

1. Introduction

Because of differences in range offsets between reflectivity and velocity data, a thin ring of velocities near the end of first trip/start of second trip that doesn't fit the adjacent velocity data may occur. This ring of "noisy" velocities can be removed via two adaptable parameters, Threshold (Fix Trip Minimum Bin) and Threshold (Fix Trip Maximum Bin). WSR-88D system changes, such as replacing the legacy RDA with the ORDA, require modification of these adaptable parameters. For RPG Software Build 9 these values were set at -3 and +1, respectively (see Figure A1).

2. Enhanced VCP 121 Adaptable Parameter Settings From Build 9 Field Test

To illustrate the noisy ring, an enhanced VCP 121 Build 9 velocity product was generated using incorrectly set values for the two adaptable parameters Threshold (Fix Trip Minimum Bin) and Threshold (Fix Trip Maximum Bin) (see Figure A2). Using the default Build 9 settings left a ring one gate deep (not shown). Field testing from Lake Charles and other sites has shown that setting the second value, Threshold (Fix Trips Maximum Bin), to +2 removes the ring completely (see Figure A3).

3. Adaptable Parameter Settings for Build 10

For fielding purposes the default value for Threshold (Fix Trip Minimum bin) is set to -3 and the value for Threshold (Fix Trip Maximum Bin) is set to +6. However, these may not be the optimal settings for the two Threshold parameters. Among many new features in Build 10 is super resolution data (discussed elsewhere). For compatibility with most of the current algorithms, super resolution data are recombined into standard resolution data using the Recombination Algorithm which is done before the MPDA dealiases velocity data. Therefore, some processing previously done by the MPDA at the RPG is now done at the RDA. Prior to the Build 10 Beta Test, the only site on which to collect Build 10 data has been the ROC's test bed WSR-88D (KCRI) thus limiting testing of the appropriateness of the settings for other sites. Figure A4 shows an example of a velocity product from KCRI with a "noisy" ring present. Figure A5 shows the same data with settings of +2 and +6 for Threshold (Fix Trip Minimum Bin) and Threshold (Fix Trip Maximum Bin), respectively. These values, while removing the noisy ring, may not be universally valid. Therefore, another test using the -3 for Threshold (Fix Trip Minimum Bin) in combination with the +6 for Threshold (Fix Trip Maximum Bin) was made (Figure 6). A comparison of Figures A5 and A6 shows only trivial differences. The most noticeable effect of the -3 and +6 values for the Threshold (Fix Trip Minimum Bin) and Threshold (Fix Trip Maximum Bin) will be a ring of missing data at the start of the

extended coverage beyond 125 n mi with the super resolution digital velocity product (see Figure A7).

Recommendation: **To reduce the ring of missing data at the start of the extended coverage, sites should try changing the Threshold (Fix Trip Minimum Bin) from -3 to +2 but keep the Threshold (Fix Trip Maximum Bin) set to +6. (See Figure A8 for sample graphical user interface screen.)**

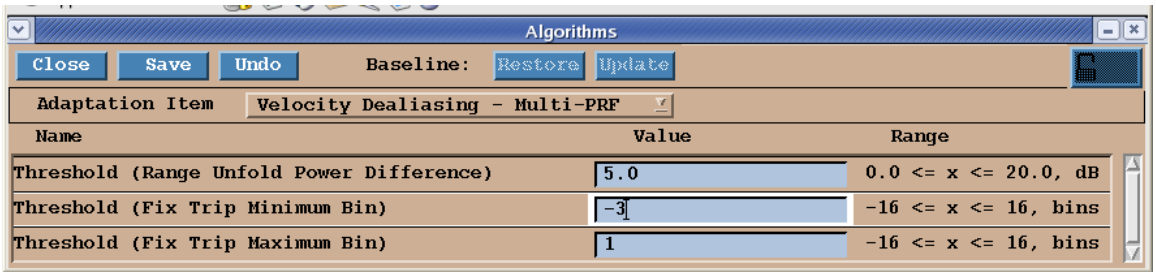


Figure A1. HCI screen for the MPDA adaptable parameters showing the values from Build 9.

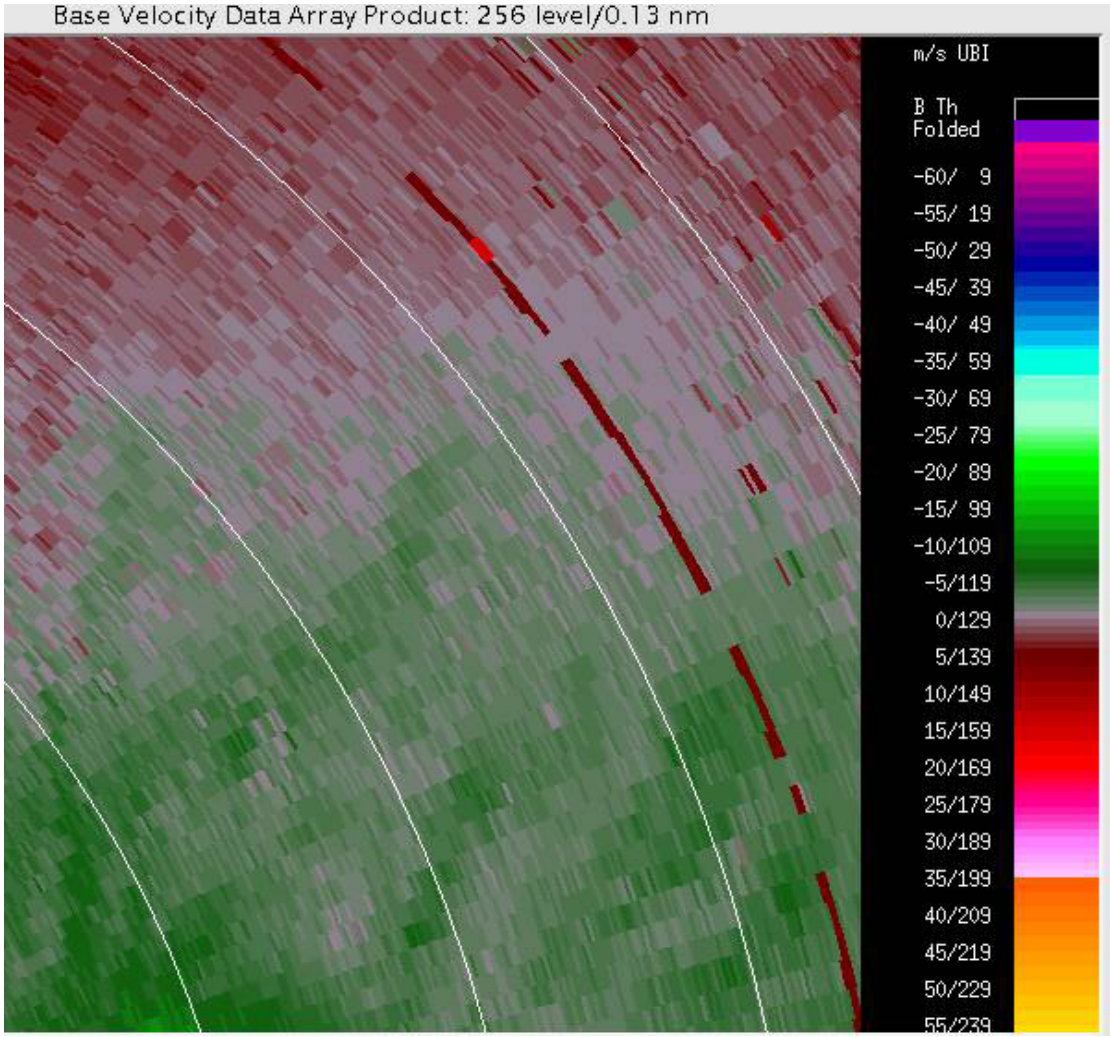


Figure A2. Example of a Build 9 digital velocity product from Lake Charles using the enhanced version of VCP 121 with incorrectly set values of -7 and -3 for Threshold (Fix Trip Minimum Bin) and Threshold (Fix Trip Maximum Bin), respectively. Range rings are every 10 n mi. Elevation angle is 0.5º.

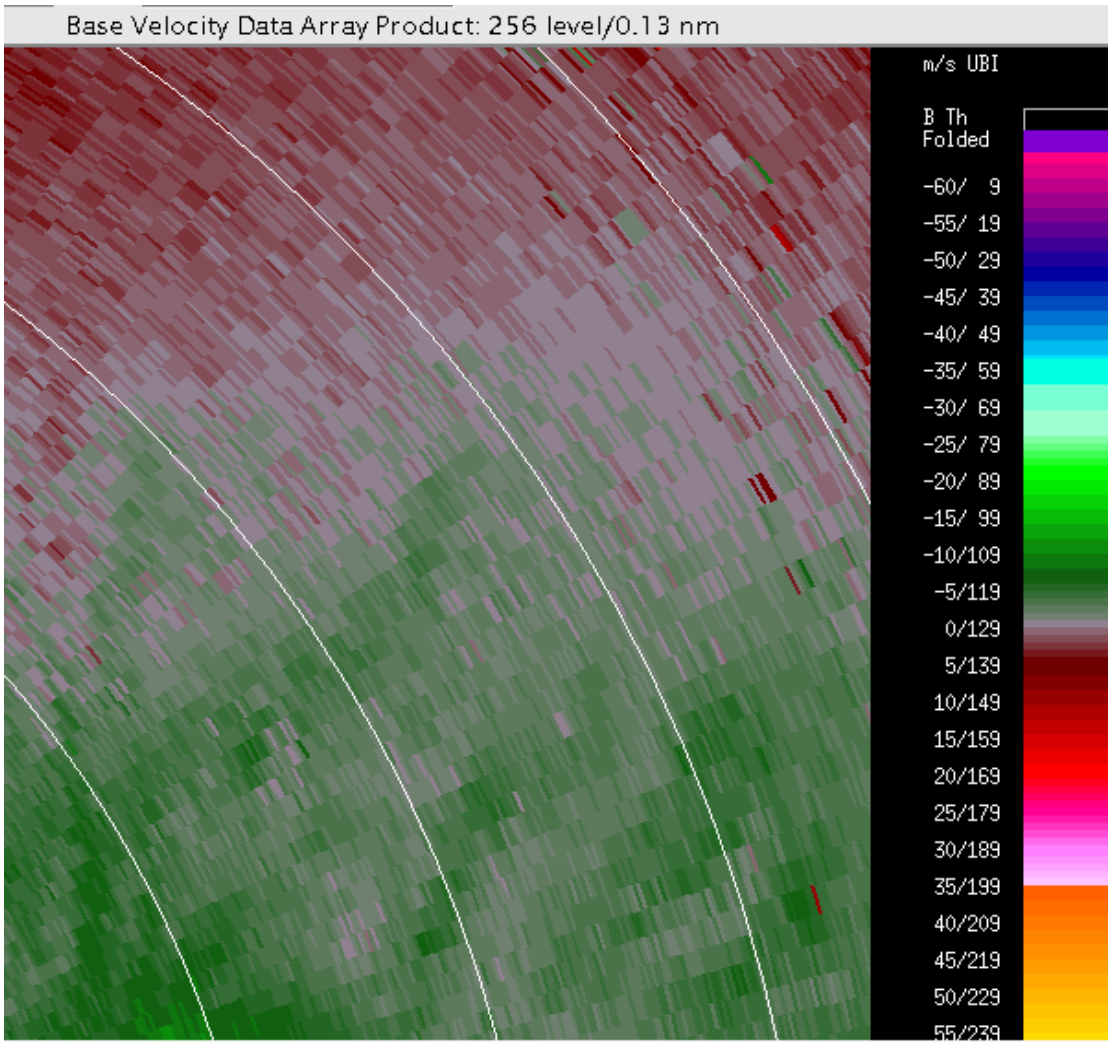


Figure A3. Example of a Build 9 digital velocity product from Lake Charles using the enhanced version of VCP 121 with values of -3 and +2 for Threshold (Fix Trip Minimum Bin) and Threshold (Fix Trip Maximum Bin), respectively. Range rings are every 10 n mi. Elevation angle is 0.5º.

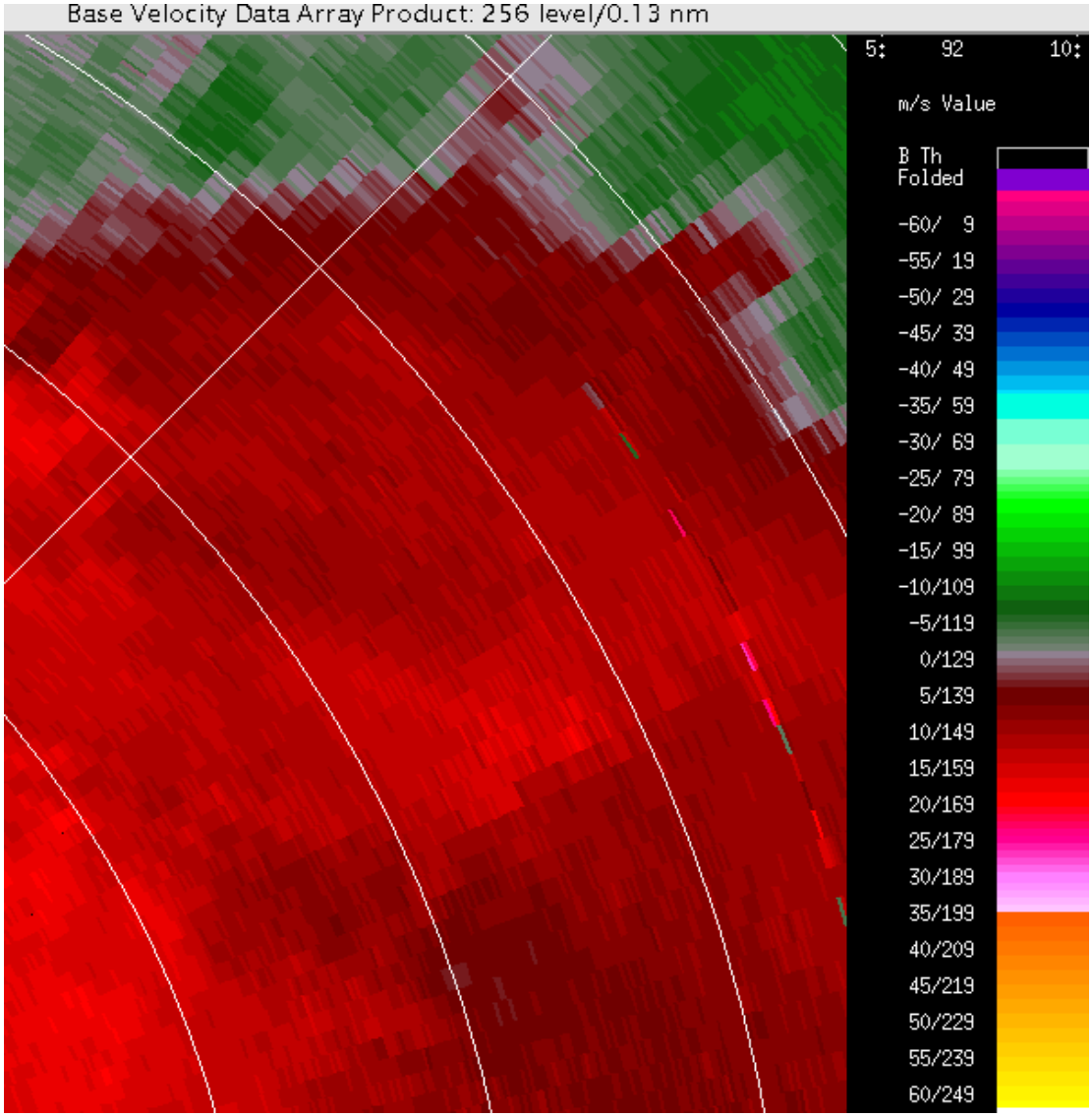


Figure A4. Example of a Build 10 digital velocity product from the ROC test bed using the enhanced version of VCP 121 with incorrectly set values of -7 and -3 for Threshold (Fix Trip Minimum Bin) and Threshold (Fix Trip Maximum Bin), respectively. Range rings are every 10 n mi. Elevation angle is 1.45º.

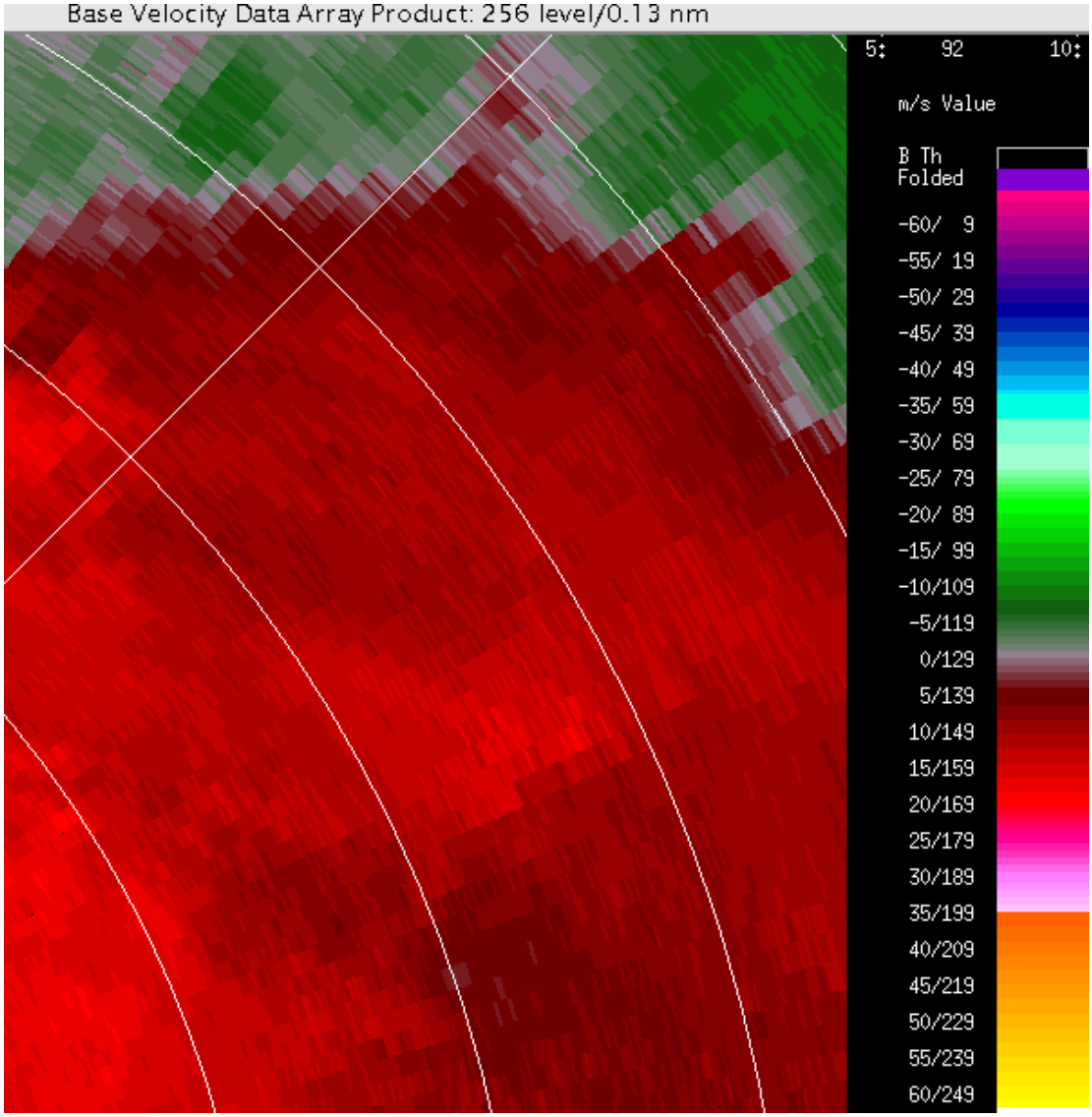


Figure A5. Example of a Build 10 digital velocity product from the ROC test bed using the enhanced version of VCP 121 with values of +2 and +6 for Threshold (Fix Trip Minimum Bin) and Threshold (Fix Trip Maximum Bin), respectively. Range rings are every 10 n mi. Elevation angle is 1.45º.

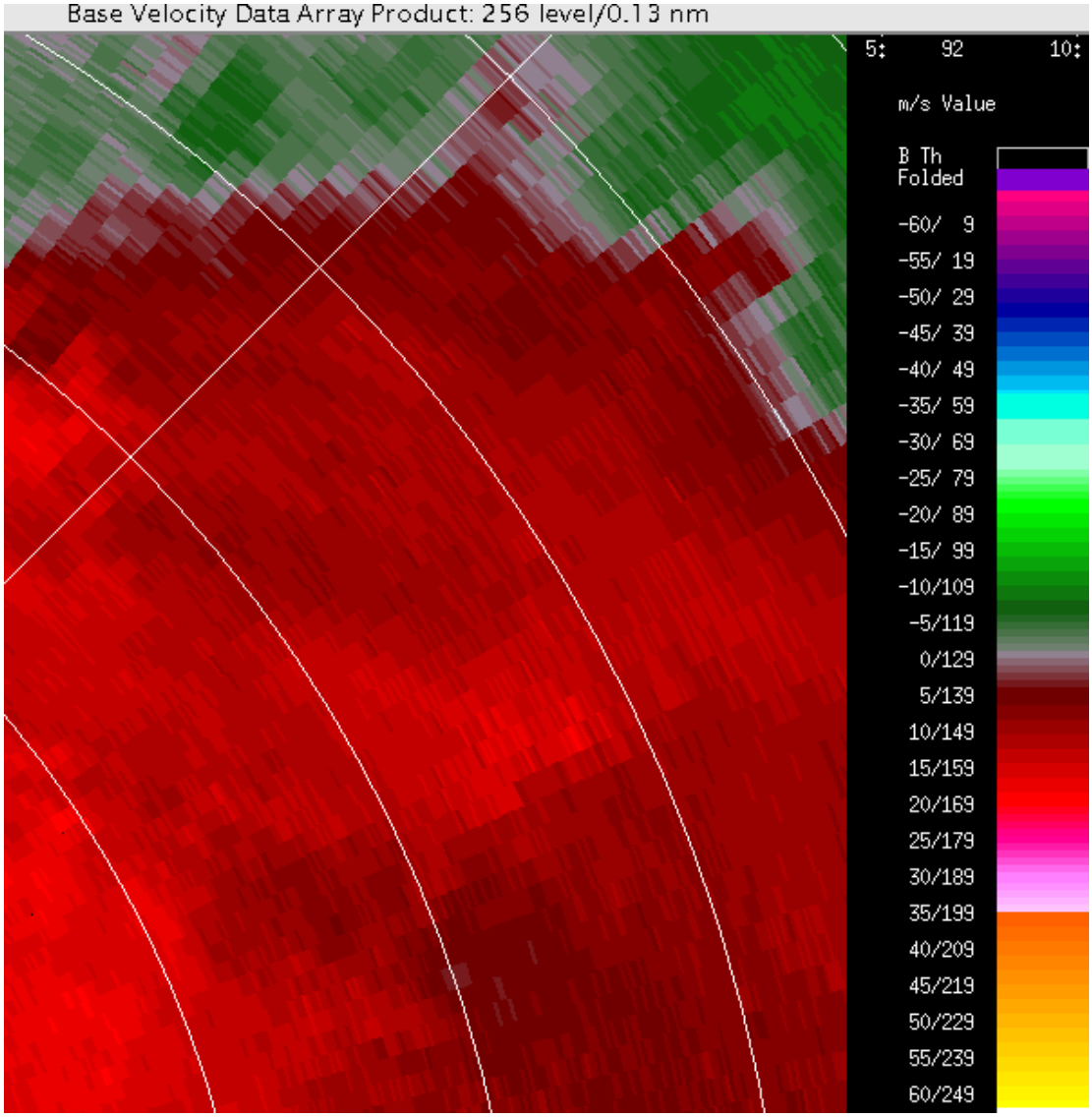


Figure A6. Example of a Build 10 digital velocity product from the ROC test bed using the enhanced version of VCP 121 with values of -3 and +6 for Threshold (Fix Trip Minimum Bin) and Threshold (Fix Trip Maximum Bin), respectively. Range rings are every 10 n mi. Elevation angle is 1.45º.

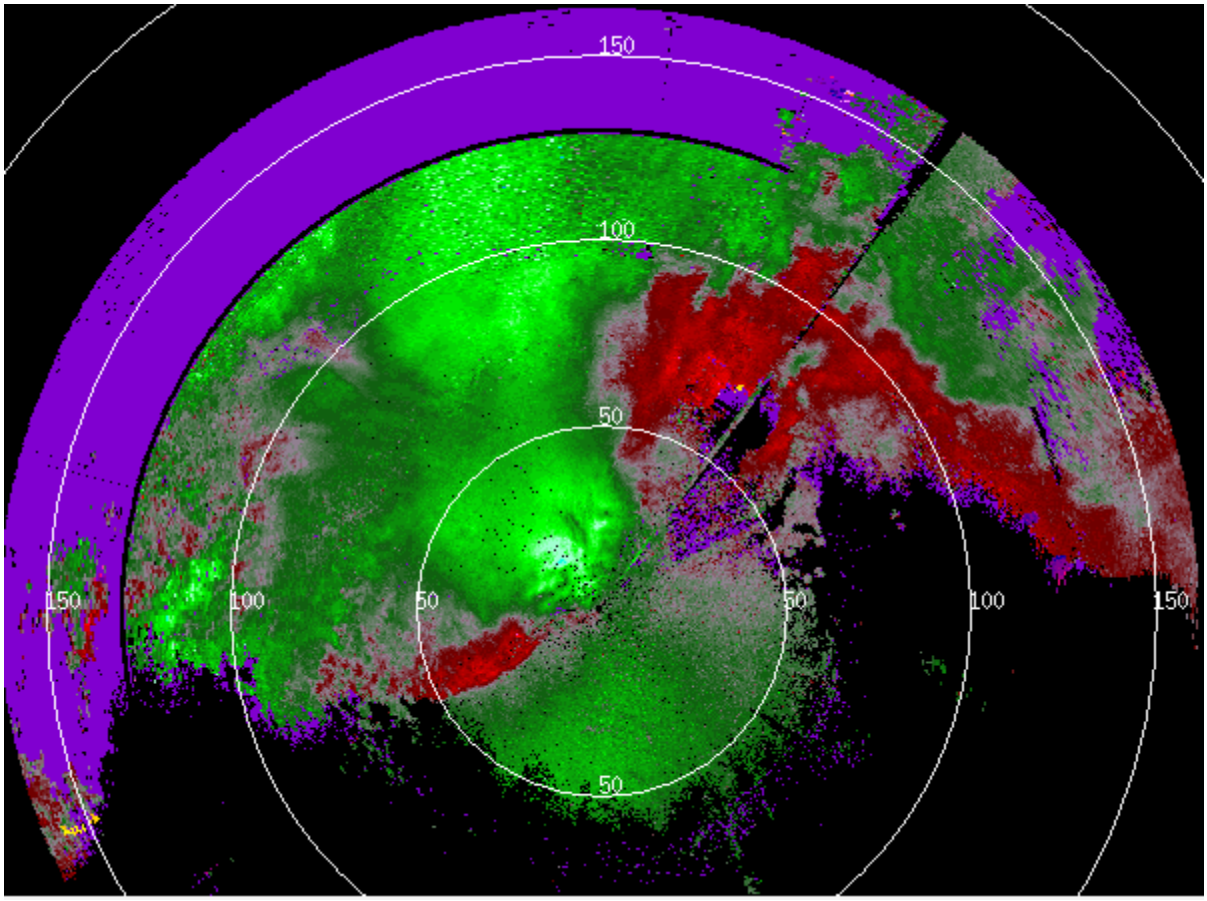


Figure A7. Example of a Build 10 super resolution digital velocity product from the ROC test bed using the enhanced version of VCP 121 with values of -3 and +6 for Threshold (Fix Trip Minimum Bin) and Threshold (Fix Trip Maximum Bin), respectively. Range rings are every 50 n mi. Note the ring of missing values around 125 n mi. Elevation angle is 0.5º.

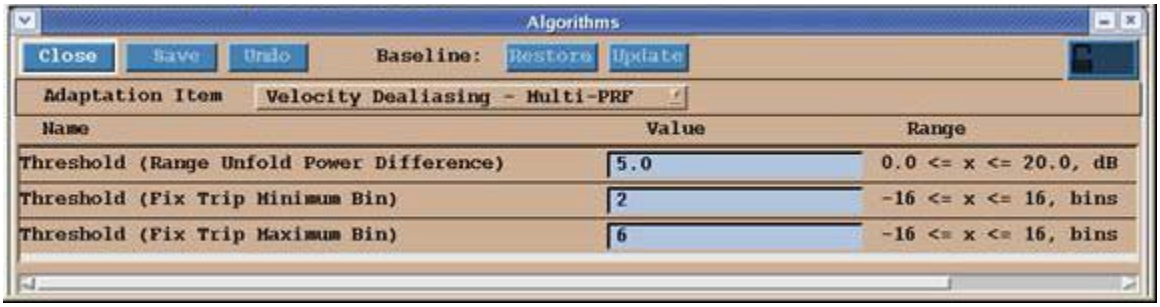


Figure A8. Graphical user interface screen for the MPDA showing suggested Build 10 settings for Threshold (Fix Trip Minimum Bin) and Threshold (Fix Trip Maximum Bin.)