ENHANCING THE FOUNDATIONAL DATA FROM THE WSR-88D: PART I, A HISTORY OF SUCCESS

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1. INTRODUCTION

Since 1993, the Radar Operations Center (ROC) has had a joint agreement with the National Severe Storms Lab (NSSL) and the National Center for Atmospheric Research (NCAR) for the purpose of improving the foundational radar data quality. This agreement, referred to as the Data Quality Memorandum of Understanding (DQ MOU), has focused on the transition of new science research to operations, and has resulted in many significant improvements. This paper illustrates the past and ongoing successes of foundational radar data quality improvements.

It is important to emphasize that the DQ MOU focuses on the signal processor aspect of the Radar Data Acquisition (RDA) subsystem. The NEXRAD WSR-88D is comprised of four main functions. The first data processing step is the RDA which receives the backscattered energy from the transmitted pulse, digitizes it into time series data, then computes the single polarization base moments of reflectivity (Z), velocity (V), and spectrum width (W) and the dual polarization variables of differential reflectivity (Zdr), correlation coefficient (CC, a.k.a. RhoHV), and differential phase (PhiDP). The second processing function, the Radar Product Generator (RPG), calculates products from the base moments and dual polarization variables. Single polarization RPG products include Vertically Integrated Liquid Water (VIL), Echo Tops (ET), Composite Reflectivity (CR), and Precipitation Processing System (PPS) and dual polarization RPG products include Hydrometeor Classification Algorithm (HCA), and the Quantitative Precipitation Estimate (QPE). The third key processing step is the communications system that disseminates products to agencies and companies that use the data. The fourth, and final, part of the system is the Principal User Processor (PUP) that provides the display for the Air Force and the Advanced Weather Interactive Processing System (AWIPS) that provides the display for the National Weather Service (NWS). Providing good quality foundational data, Z, V, W, Zdr, CC, and PhiDP is essential because not only is it used as input to the all RPG products, but also it is ingested into models to improve their performance (Xue, 2011) and it is used as input to Warnings on Forecast (Stensrud, 2009).

The past successes of the DQ MOU include capturing and utilizing time series data, validating an improved clutter filter that was part of the RDA upgrade, mitigating range folding through the first range/velocity mitigation algorithm using phase encoding, and automatically detecting anomalous propagated induced clutter in addition to ground clutter. Some of the current efforts addressed in this paper are a second range/velocity mitigation effort utilizing staggered pulse repetition frequencies, improved spectrum width calculations, and continued improvements to the clutter detection algorithm.

2. SUPPORTING INVESTIGATIONS; Level I Recording

Level I data, also known as the digitized time series data of the In-phase (I) and Quadrature (Q) components of the returned signal, are the most basic and least processed data of the weather radar system. It is a very large amount of data, generating 10 GB per hour for single polarization and 20 GB per hour for dual polarization. It is the input to all of the foundational data improvements and the efforts to record it have been going on since early in the 1990s.

The DQ MOU supported Level I recording before the RDA upgrade by collaborating with NCAR to develop the Archive 1 Data Analyzer (A1DA) that was connected to the Hardwired Signal Processor (HSP) of the original WSR-88D. Through this effort, the Level I data from the central Oklahoma tornado outbreak on 3 May 1999 data was captured. With the ORDA upgrade, the Sigmet (now Vaisala Sigmet) RVP8, the Time Series Application Programming Interface (TS API) provided the infrastructure for easier Level I data recording. In 2003, Level I

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recording with the RDA began as a ROC application using the TS API. In 2005, the ROC transitioned to using Sigmet's licensed TSArchive utility (Rhoton, 2005). Soon after, the DQ MOU supported collaboration with NCAR resulted in the stand alone application, Ts2File, that is used today.

Having recorded Level I data available advances the transition from new science research to operations. Sharing the data sets with NCAR and NSSL provides research organizations with data sets collected in an operational environment. Shared data sets also provides the ROC with test data that has known, or expected, results that were developed by the research organizations. On occasion, the ROC has compared bin by bin results from the ROC RVP8 software with output from research applications running on a different platform. Finally, recorded Level I data coupled with the ROC capability to play back the data through the RVP8 allows for testing software changes with known data sets.

3. ENSURING CLUTTER FILTER QUALITY; GMAP Validation

With the RDA upgrade, the clutter filtering technique changed from a five pole elliptic filter to the Gaussian Model Adaptive Processing (GMAP) clutter filter developed by Sigmet. The ROC evaluated the new GMAP clutter filter with the help of NCAR and NSSL via the DQ MOU.

Since the clutter filter evaluation occurred during the RDA Level I recording capability development, limited data cases were available. NSSL and NCAR supported the evaluation by providing Level I data to the ROC. NSSL provided additional support by reprocessing the same Level I data set using the Legacy five pole elliptic clutter filter for comparison to the GMAP clutter filtered data generated by the ROC. In order to determine clutter suppression levels for reflectivity data, the team performed regression analysis of filtered versus unfiltered results. Figure 1 shows a regression scatter gram of GMAP filtered reflectivity estimates versus the non-filtered results for the same input time series recorded on April 17, 2004. Figure 2 shows the MATLAB generated difference field of the reflectivity images without clutter filtering applied and with GMAP clutter filtering applied. This evaluation effort showed that GMAP met clutter suppression and bias requirements of the NEXRAD WSR-88D (Ice, 2005), ensuring that the new clutter filtering approach did not adversely affect the foundational data.

4. MITIGATING RANGE FOLDING; S/Z (8/64) Phase Encoding

Developed by NSSL, the range unfolding algorithm, Sachidananda/Zrnic (SZ) (8/64) Phase Encoding (SZ-2), was the first new science algorithm implemented on the RDA. SZ phase encoding was initially proven on weather radar through collaboration between NSSL and NCAR. After that, NSSL refined the algorithm for operations while NCAR provided further evaluations. The ROC implemented SZ-2 for operational use and deployed it in 2007.

SZ-2 provides the ability to recover 2nd trip echoes and reduces the number of ranged folded bins (purple) to less than 10%. SZ-2 was combined with an RPG-based multi-PRF scheme, MPDA, to nearly eliminate range folding.

On 30 December 2006 around 0200 Z, a major winter storm nearly covered Oklahoma. The ROC test-bed radar, KCRI, was running a version of MPDA that used SZ-2 as one of its multiple Doppler scans and KTLX, located about 18 km (10 n mi) east-northeast of KCRI, was running an older version of MPDA that did not use SZ-2. Figure 3 illustrates the improvement to MPDA using SZ-2. Upper left is KTLX Reflectivity from the Surveillance scan. Upper right is the KTLX MPDA using non-phase encoded Doppler Scans with a minimum PRF of 850 Hz, note all the purple that indicates range folded data. Lower left is the SZ-2 only scan from KCRI using PRF of 1300 Hz; note the ring of purple where clutter overlays the beginning of the second trip and the recovered signal beyond the ring. Lower right is the KCRI SZ-2 enhanced MPDA result; note that range folded signals are virtually eliminated (Zittel, 2008).

SZ-2 was the first signal processing (RDA level) algorithm successfully transferred from research to operations providing greatly reduced range folding (Saxion, 2007). The collaboration between the ROC, NSSL, and NCAR helped to ensure a smooth transition to the operational environment. It is one of the shining examples of the successes of the DQ MOU.

5. IDENTIFYING ANOMOLOUSLY PROPAGATED CLUTTER; Clutter Mitigation Detection

The NCAR developed Clutter Mitigation Detection (CMD) algorithm is another DQ MOU success because it relieved forecasters from the burden of dynamically identifying regions for clutter filtering during times when atmospheric changes caused anomalously propagated clutter. CMD automatically identifies if a weather signal is significantly contaminated by clutter. If so, it is flagged for the application of the clutter filter. Figure 4 shows a comparison of a weather event from the single polarization WSR-88D without and with CMD enabled. The upper panels are reflectivity and velocity images from a weather event with AP clutter that has the usual bypass map determining where to apply clutter filtering. The lower panels show the same event with CMD enabled which detects the AP clutter then applies GMAP to clutter filter. Note the reduced areas of zero velocity values indicating that the AP clutter has been successfully filtered. In 2009, the single polarization version of CMD was successfully deployed in Build 11.1 (Ice, 2009).

The dual polarization upgrade was developed from Build 10, the release prior to the release with CMD. This means that when dual polarization is deployed in Build 12, the CMD capability will disappear. The ROC is re-implementing CMD for the dual polarization upgrade which will be available in Build 13 that has a scheduled deployment for July 2012. Figure 5 shows the results of an early test case from 28 June 2011 when a small weather event passed over the dual polarization test bed radar, KOUN, located in Norman, OK. The images on the left are reflectivity, velocity, and differential reflectivity without clutter filtering applied. The images on the right are reflectivity, velocity, and differential reflectivity after CMD identified both the AP and ground clutter and flagged these regions for clutter filtering. After applying GMAP in the areas CMD identified as clutter, areas with high reflectivity values, zero velocity values, and noisy differential reflectivity values were removed, indicating that CMD properly identifying clutter.

CMD's greatest success lies in the fact that it makes forecasters' job easier. However, since CMD identifies where clutter is contaminating weather signals, the clutter filter is only applied where it is needed, further improving foundational data quality. Again, the DQ MOU provided the overarching plan for integrating this new science into the operational environment.

6. MITIGATING VELOCITY ALIASING; Staggered PRT

NSSL developed the Staggered Pulse Repetition Time (Staggered PRT or SPRT) velocity dealiasing algorithm. It is a method of switching between two different pulse repetition times in order to recover higher velocities. The basic algorithm has been implemented and is non-operational in the WSR-88D. SPRT has been shown to work best at upper elevation scans and is best suited for replacing the Batch Cuts, the mid-level scans of current WSR-88D Volume Coverage Pattern (VCP) definitions. With SPRT, longer PRTs may be used, reducing range folding, while increasing the unambiguous velocity so that it is the same as uniformly pulsed higher PRTs. Figure 6 shows an example of this. The top image is the reflectivity from the long PRT of the Batch cut scan. The lower left image is velocity from the short PRT of the Batch cut. Note the areas of range folding, indicated by purple. Some of the overlaid echoes are recovered due to the Batch Cut processing technique. The lower right image is velocity from two interleaved lower PRTs. This provides the same maximum velocities as Batch cut but with no range folding (Torres, 2009).

The next step is to implement a clutter filter that will work with the non-uniform spaced SPRT transmission scheme. The NSSL has a clutter filter developed and has provided the algorithm to the ROC. Unfortunately, this work has been delayed due to the dual polarization upgrade. SPRT is expected to be deployed in Build 14.

7. IMPROVED SPECTRUM WIDTH; Hybrid Spectrum Width

The NCAR developed a method to improve spectrum widths by reducing the bias and variance of the estimates called the hybrid spectrum width (HSW) (Meymaris, 2009). This is achieved by determining which estimator would perform best using criteria such as number of pulses and estimated magnitude of the spectrum width. This algorithm was implemented by the ROC and is currently being tested. Figure 7 shows a comparison of the currently deployed spectrum width estimator with the HSW. The top image shows reflectivity. Lower left is the current spectrum width field. Lower right is spectrum width that was calculated using HSW. Note the smoother field, especially at the outer edges, in the HSW image. The scheduled deployment is for Build 13 which should begin deployment in July 2012.

The DQ MOU is funded by the three agencies that support the NEXRAD program, National Weather Service (NWS), Federal Aviation Administration (FAA), and the United States Air Force (USAF). Therefore, it is important that the results from new science identified in the DQ MOU support the mission of all agencies. The HSW is especially useful for turbulence algorithms which support the FAA's mission.

8. SUMMARY

When thinking of the future (Ice, 2011), it is also necessary to consider the past. Have past efforts provided real improvements for the NEXRAD WSR-88D? The answer is clearly, yes. The DQ MOU has identified and transitioned six tasks that have resulted in improvements in all three single polarization base moments, Z, V, and W, with future enhancements identified to improve the newly deployed dual polarization variables. Zdr, CC, and PhiDP. Through the DQ MOU, the collaboration between the ROC, NSSL, and NCAR has resulted in improved range, higher velocity, less clutter contamination, and improved spectrum widths. It provided the support to verify that the RDA upgrade base moments and new GMAP clutter filter continued to meet WSR-88D requirements. And, it has provided a means to record Level I data which is critical in the process of transitioning new science from research to operations. In the past, the NWS, FAA, and USAF have provided resources needed for improving foundational data resulting in better foundational data for use in models, forecasts and warnings. This helps the NEXRAD program meet its mission of protecting lives and property.

9. ACKNOWLEDGEMENTS

The authors would like to recognize all those who have contributed to the past and current successes of the DQ MOU. We would especially like to recognize those who had the foresight to establish this collaboration, Mr. Frank Pratte, Dr. Jeffery Keeler, and Dr. Dusan Zrnic.

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Appendix – Tables and Figures

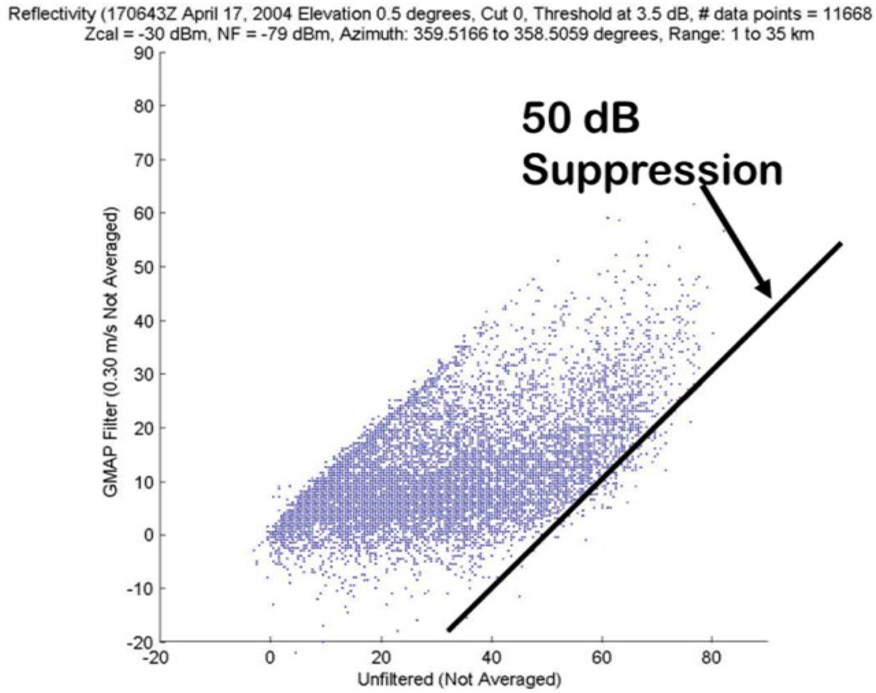

Figure 1 - Reflectivity Scatter gram - April 17, 2004

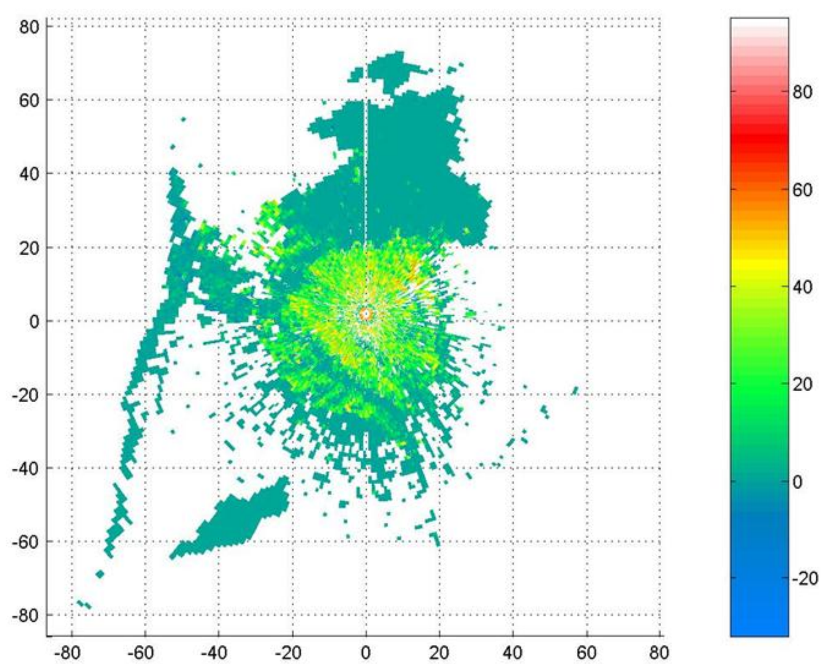

Figure 2 - Reflectivity difference between unfiltered and GMAP filtered Surveillance scan - April 17, 2004

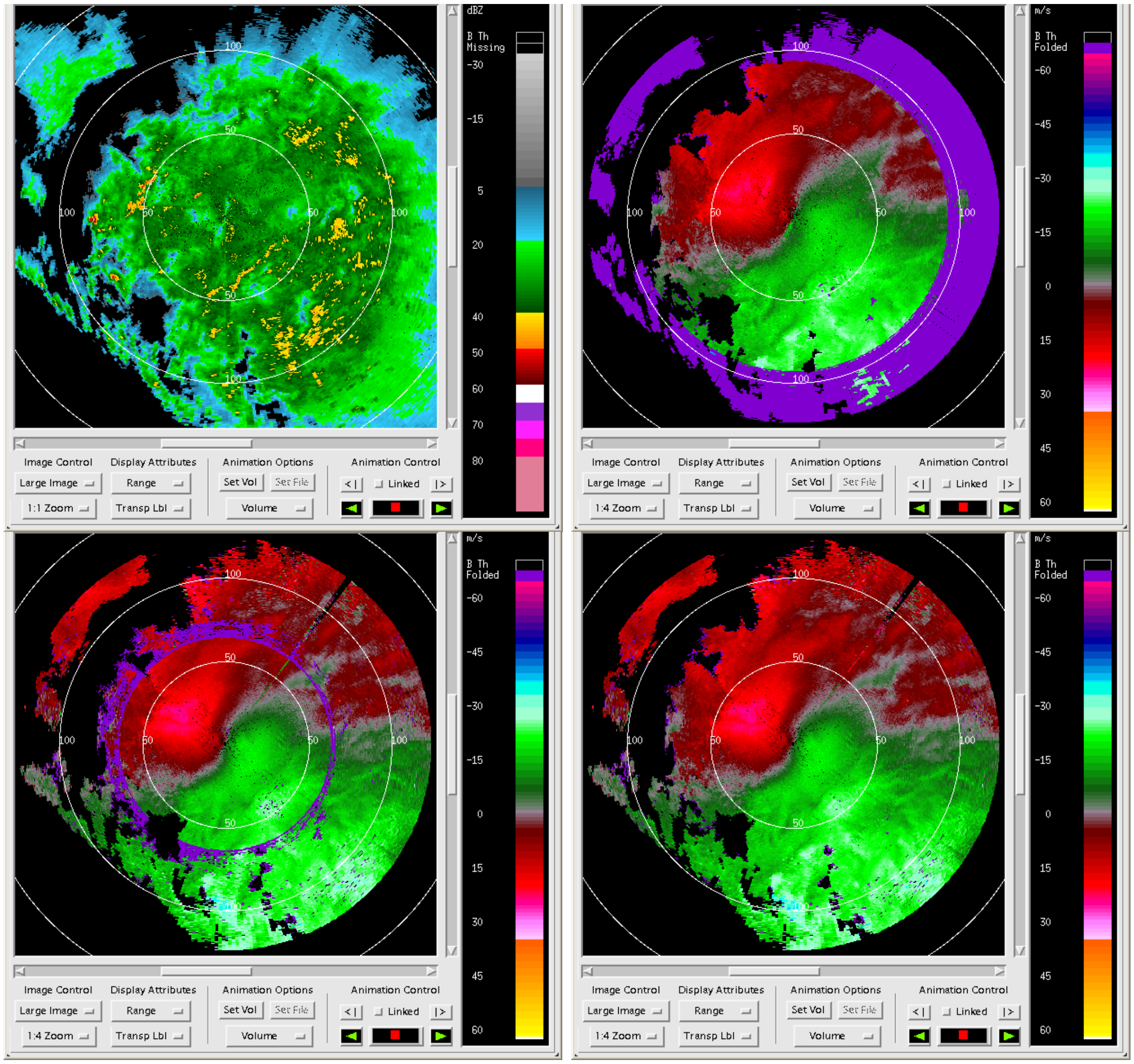

Figure 3 – Sachidananda/Zrnic (8/64) Phase Encoding with MPDA.

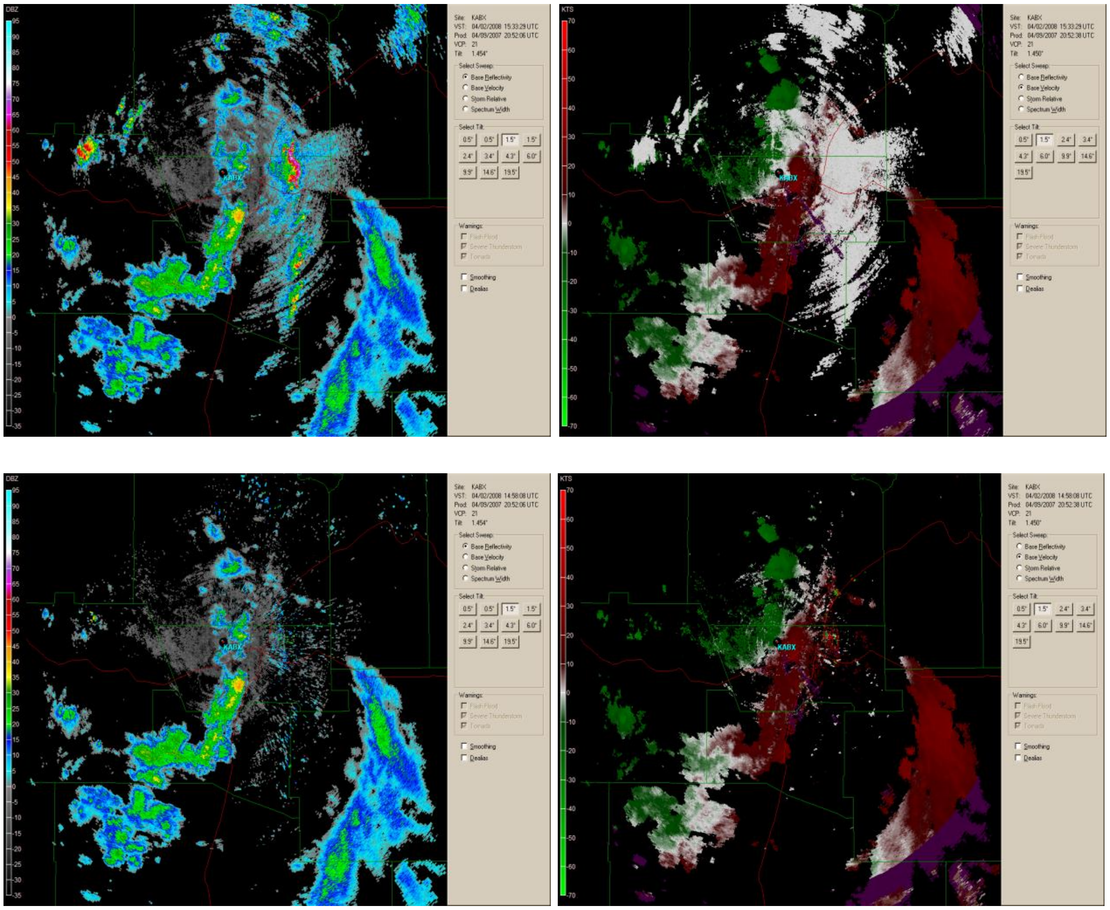

Figure 4. Clutter Mitigation Detection (CMD) for single polarization.

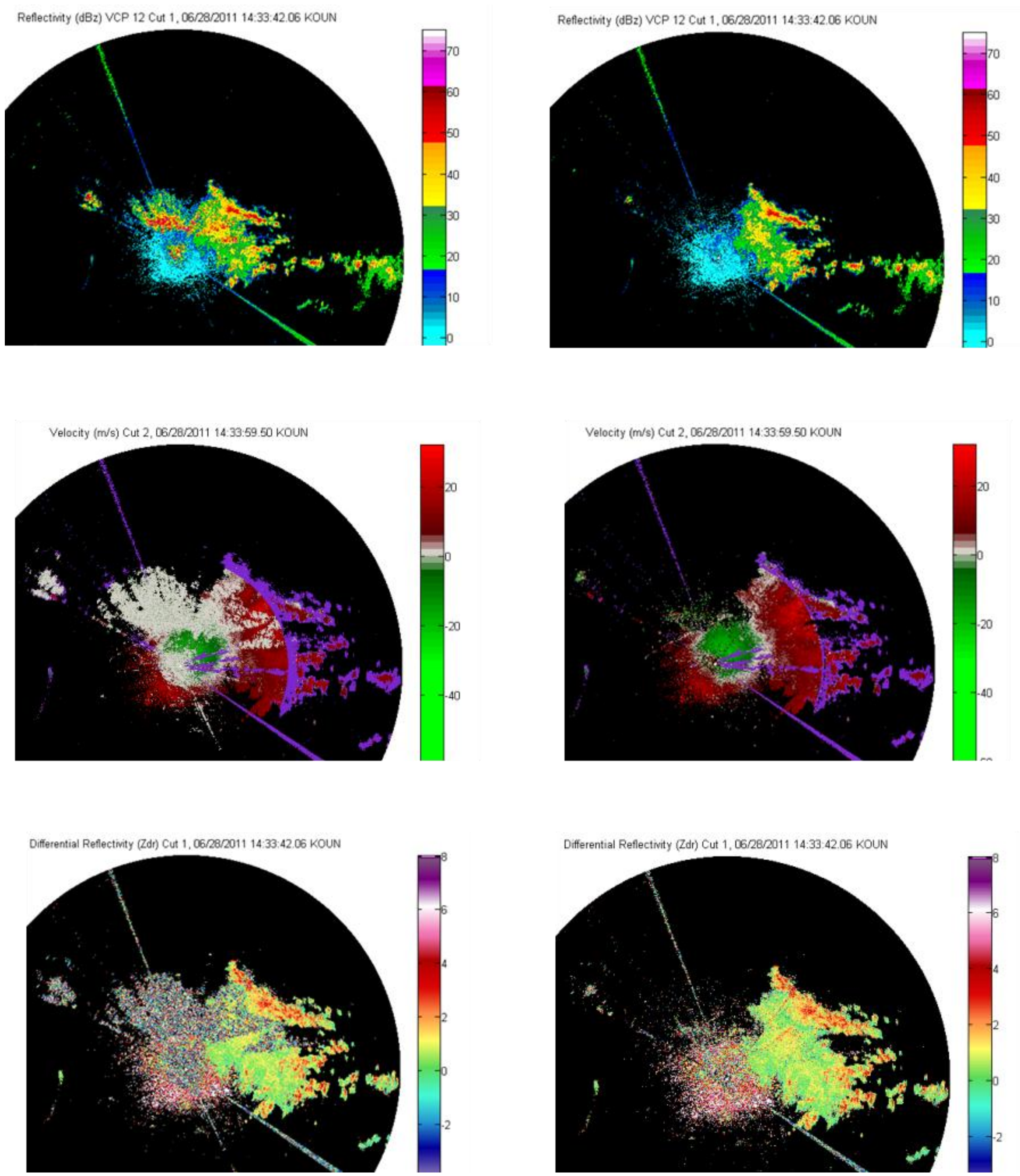

Figure 5. Clutter Mitigation Detection (CMD) for dual polarization.

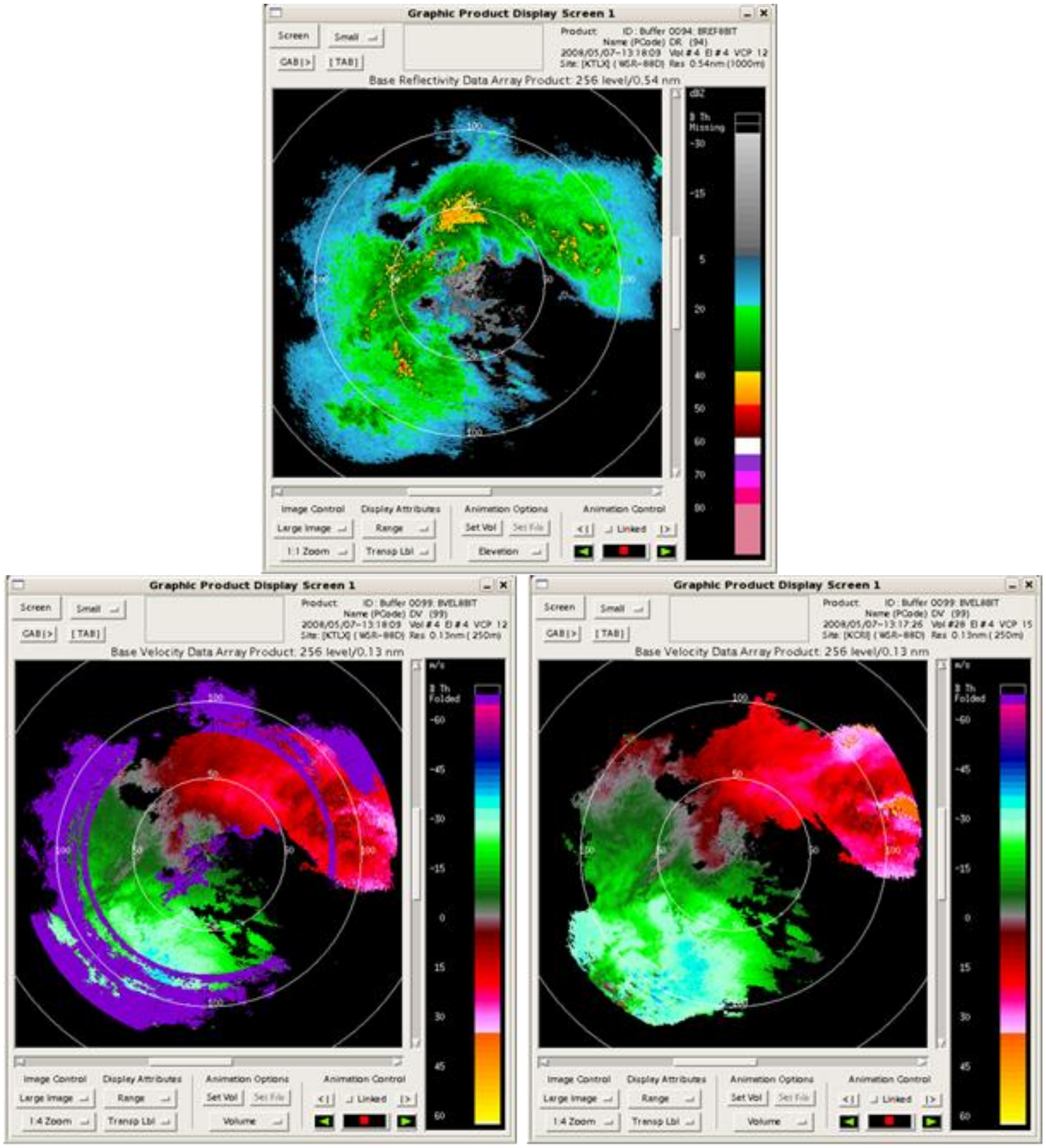

Figure 6 – Staggered PRT

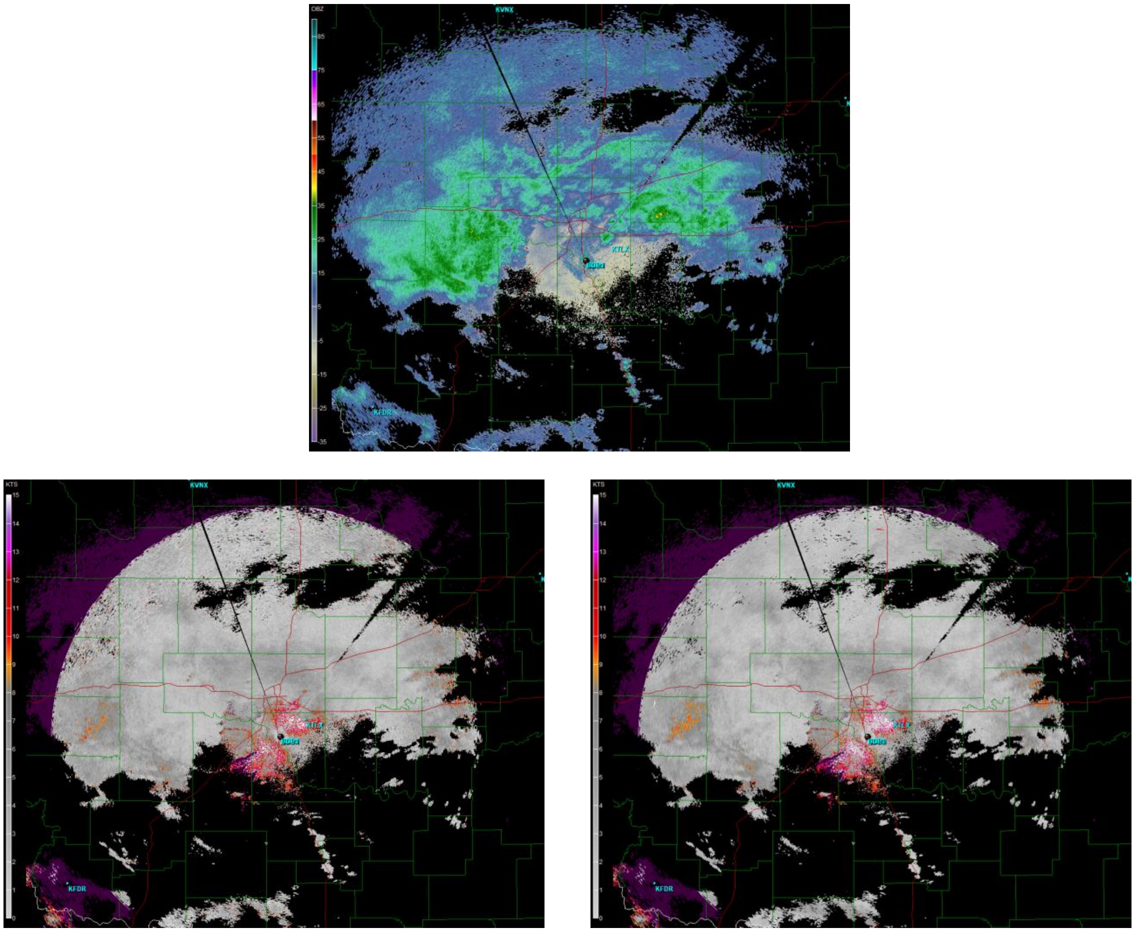

Figure 7 – Hybrid Spectrum Width