P4R.10 A FIRST LOOK AT THE OPERATIONAL (DATA QUALITY) IMPROVEMENTS PROVIDED BY THE OPEN RADAR DATA ACQUISITION (ORDA) SYSTEM

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1. INTRODUCTION

The Open Radar Data Acquisition (ORDA) project continues to progress through final development and testing. A vital element of testing includes a data quality assurance component. Execution of this component falls to a multi-disciplined team composed of both Legacy RDA and ORDA technicians and engineers, as well as radar meteorologists. One facet of this testing involved using a portable ORDA (Porta-ORDA) receiver/signal processor, installed adjacent to the Legacy system at three "operational" radar locations to support data collection. The meteorologists collected data by quickly "switching" between the Legacy RDA and the Porta-ORDA systems, thereby facilitating data comparison during the same weather regime. These data were processed by a Radar Product Generator (RPG) and the resulting products were displayed, in real-time, on an Open Principal User Processor (OPUP) system which allowed timely, side-by-side comparisons.

These initial data comparisons provided visual proof of the data quality improvements expected from ORDA. The improvements resulting from the new clutter suppression technique used by ORDA were especially noticeable. This paper provides an overview of this new clutter suppression technique, including examples of Legacy RDA and ORDA clutter suppression processing and capabilities, and provides side-by-side comparisons of the resulting Legacy and ORDA products highlighting these improvements.

Additional discussions and examples presented include: improved Bypass Map resolution; increased ORDA sensitivity in long pulse; and the contributions of new hardware and software which promote improved operational reliability and system maintainability. Finally, a brief discussion of future enhancements made possible by ORDA is presented.

Further information in the form of statistical/objective analysis and discussion are presented in two Radar Operations Center (ROC) Applications Branch contributions to this conference.

2. TWO CLUTTER SUPPRESSION SOLUTIONS

One of the most noticeable improvements in data quality is the result of ORDA's new clutter suppression technique. To understand the underlying processing improvements and reduction in moment estimation bias provided by the ORDA solution, a brief review of the Legacy RDA clutter suppression process and an overview of the ORDA's clutter suppression technique are in order.

2.1 *Review of Legacy Clutter Suppression*

The Legacy WSR-88D Infinite Impulse Response (IIR) clutter suppression filter was designed to reduce signal power whose mean radial velocity is at or near zero knots. To do this, the clutter suppression filter reduces the signal power within a "notch width" centered about the zero mean radial velocity value. This reduction in signal power effectively decreases the clutter's power contribution in the given range bin. The goal of clutter suppression is to reduce only the power return contributed by clutter targets from the range bin prior to the calculation of the base data estimates. Therefore, for each range bin in areas where clutter suppression is in effect, the portion of the power return within the selected notch width will be reduced (filtered), as represented in the simplified conceptual model presented in Figure 1 (Chrisman et al., 1995).

To maintain meteorological return integrity, only the signal power whose radial velocity falls within the notch width (See Table 1) is reduced. The

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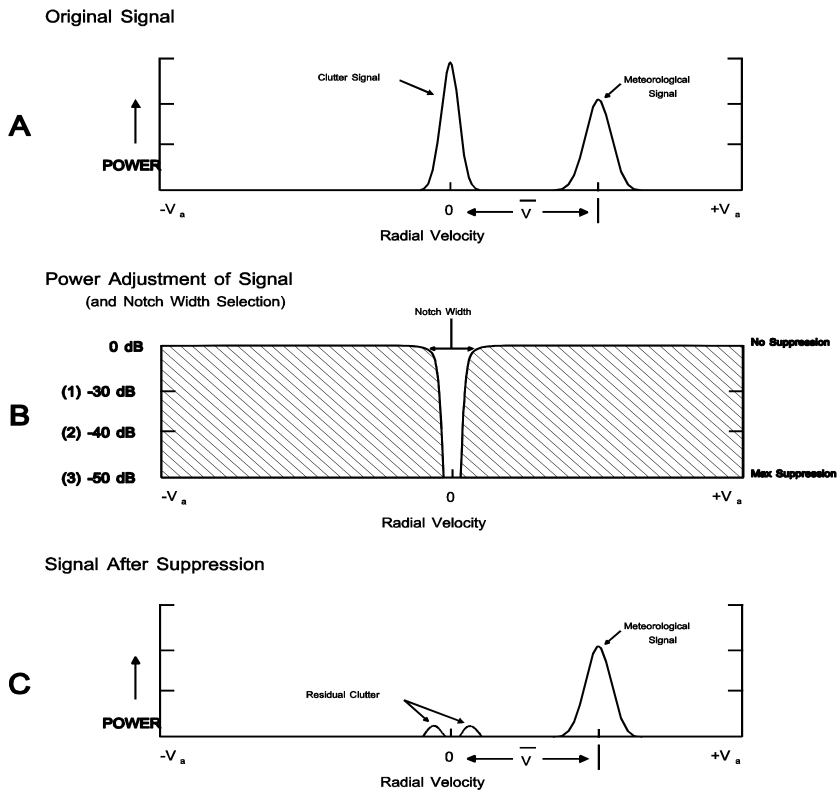

Figure 1. Simple Conceptual Model of Legacy Filter

A. A depiction of the input power for a given range bin. The clutter has a radial velocity centered around zero and the meteorological return is offset from zero due to its radial velocity.
B. Represents the clutter filter with a notch width centered on zero radial velocity. The scale represents the amount of power reduction, from 0 dB (no power reduction) to -50 dB (maximum power reduction), applied within the notch width.
C. A diagram of the resulting power after the algebraic addition of the signal from A and the power reduction factor from B (A+B=C).

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Table 1: Notch Width Selections and Suppression Values

Channel	Low		Medium		High	
	kts	dB	kts	dB	kts	dB
Surveillance	3.38	~30	4.85	~40	6.79	~50
Doppler	4.58	~30	6.05	~40	8.92	~50

notch widths vary based on the level of suppression selected by the operator and the sampling characteristics being employed during data collection. For example, during the first two elevations of VCP 11 the high notch width selection for surveillance mode is 6.79 kts. However, the sampling characteristics of Split cut mode for the lowest two tilts result in an effective notch width of approximately 12 kts. For Batch cuts it is much worse. Due to antenna rotation rates and the sampling limitations of Batch mode, the effective notch width of high suppression for these elevations is approximately 30 kts. This means high suppression (Notch Width Selection 3) applied to the Batch tilts will cause a 50 dB reduction in targets whose radial velocity is less than approximately +15 knots. This has a major impact on the base reflectivity data which cascades through all reflectivity-based products. This clutter suppression approach works well in preserving meteorological return and providing accurate moment estimates when the radial velocity of the meteorological return falls outside the effective notch width. However, when any or all of the meteorological return has a velocity that falls within the effective notch width, that portion of the meteorological return will be subjected to filtering. This results in either significantly reduced or below threshold (missing) reflectivity estimates and missing velocity data or velocity moment estimates biased away from zero (Figure 2). In Figure 2, note the diminished reflectivity return in image C and the near absence of the zero velocities in image D.

2.2 *Overview of the ORDA Clutter Suppression Technique*

Clutter filtering in the ORDA is accomplished using a WSR-88D-tuned version of the SIGMET Gaussian Model Adaptive Processing (GMAP) clutter filtering technique. Unlike the Legacy IIR clutter filter that indiscriminately reduces power from all return whose radial velocity falls within the effective notch width, GMAP is applied in the frequency domain and uses iterative algorithm processing to reduce the power centered around zero within a specified clutter spectrum width. Additionally, GMAP interpolates over any removed power components, thus reconstructing the spectrum of any removed meteorological-based power return. This step significantly reduces clutter filter-induced bias in the base data estimates, thereby improving the accuracy of these estimates.

The fundamental tenet of GMAP is that clutter targets produce a Gaussian frequency distribution around zero velocity with a known, narrow spectrum width. The starting spectrum width (seed) value used in the WSR-88D is 0.7 m/s. For each range bin, GMAP processes the frequency spectrum to identify the power centered on zero velocity. Using this power value, GMAP calculates a clutter Gaussian having a 0.7 m/s (seed value) spectrum width. GMAP then applies this initial clutter Gaussian to the frequency spectrum. If needed, GMAP iteratively recalculates the clutter Gaussian using successively narrower spectrum width values until only clutter power is defined within the clutter Gaussian. All power points within the final resultant clutter Gaussian are assumed to

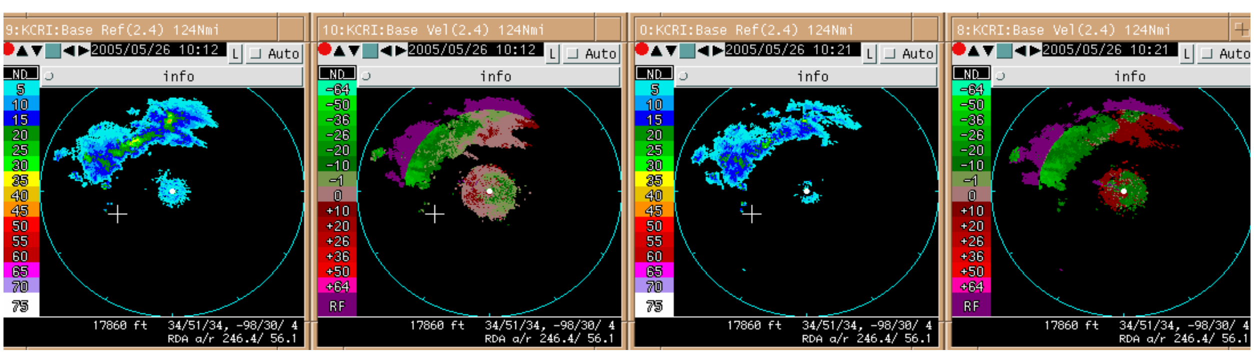

Figure 2. Example of Data Estimate Bias Caused by IIR Clutter Suppression

A. Legacy Base Reflectivity - Clutter Suppression Not Active
B. Legacy Base Velocity - Clutter Suppression Not Active
C. Legacy Base Reflectivity - Clutter Suppression Active, All Bins High
D. Legacy Base Velocity - Clutter Suppression Active, All Bins High

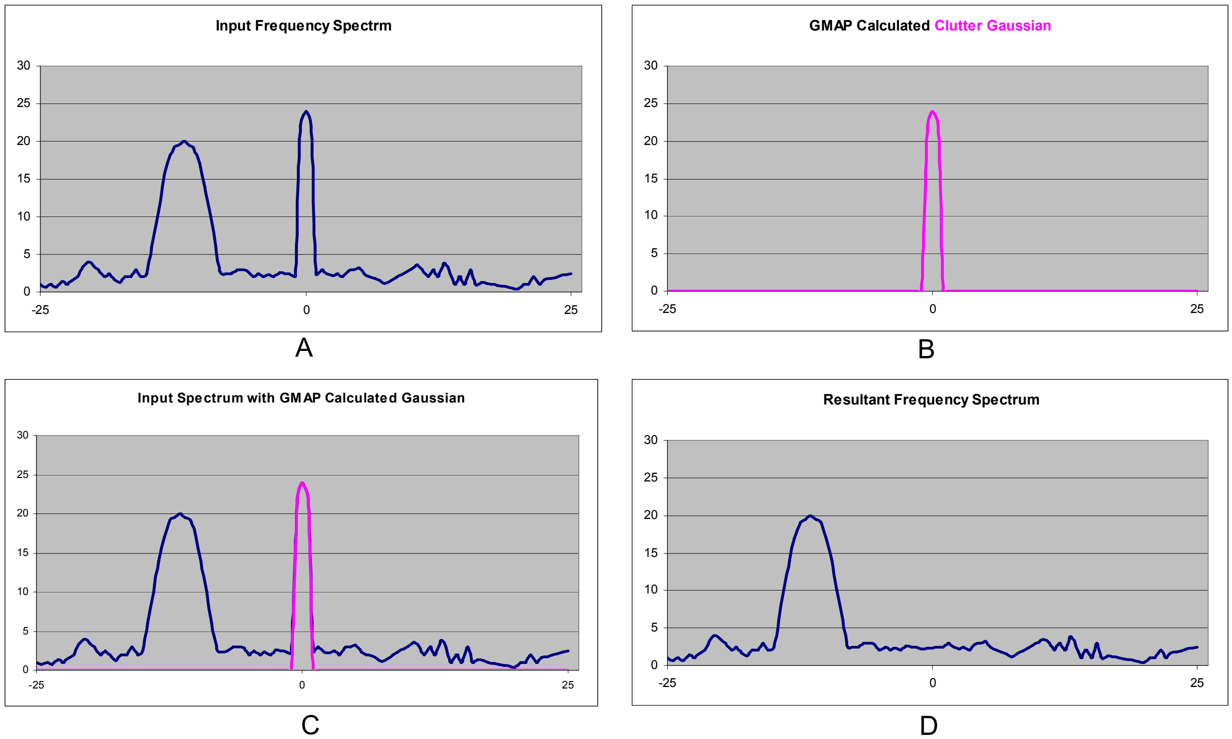

Figure 3. Conceptual Model of GMAP Clutter Filter

A. Input Frequency Spectrum with Weather and Clutter Return
B. GMAP Calculated Gaussian Clutter Spectrum
C. Gaussian Clutter Spectrum overlaid on Input Frequency Spectrum
D. Resultant Frequency Spectrum Used to Calculate the Base Data Estimate

be from clutter and are removed from the spectrum (Figure 3). NOTE: Unlike the Legacy IIR filter, the amount of signal removed is automatically adaptive and not dependent on the operator-selected level of suppression (notch width).

Both the IIR clutter filter used in the Legacy RDA and GMAP work extremely well in situations when the meteorological returns are offset from zero velocity, as depicted in Figure 3. However, when the meteorological return includes components that are at or near zero, GMAP performs much better. GMAP adapts its filter, on a bin-by-bin basis, based on the clutter's power and spectral shape. Additionally, GMAP provides the capability to "rebuild" the power spectrum of any removed meteorological return, thereby significantly reducing clutter filter-induced bias in the base data estimates.

To achieve this, GMAP analyzes the resultant frequency spectrum (after signal removal from within the clutter Gaussian) to determine if there is any meteorological-like power return above the calculated noise level. If there is power above the noise level, GMAP calculates a Gaussian weather model using these points. This weather model is applied to the frequency spectrum to interpolate over the removed "clutter" power components. GMAP repeats this process (applying a weather Gaussian and recomputing the spectrum) until the computed power changes by less that 0.2dB and the velocity changes by less than 0.5% of the Nyquist velocity (Siggia and Passarelli, 2004). The result is that this process effectively rebuilds the meteorological return whose spectrum overlaps the clutter Gaussian (Figure 4). This significantly reduces the clutter-filter induced bias that weakens reflectivity estimates and causes velocity data to be biased away from zero.

Although not widely known, the WSR-88D total suppression solution relies on a two step process to achieve the amount of suppression required to remove high power terrain targets.

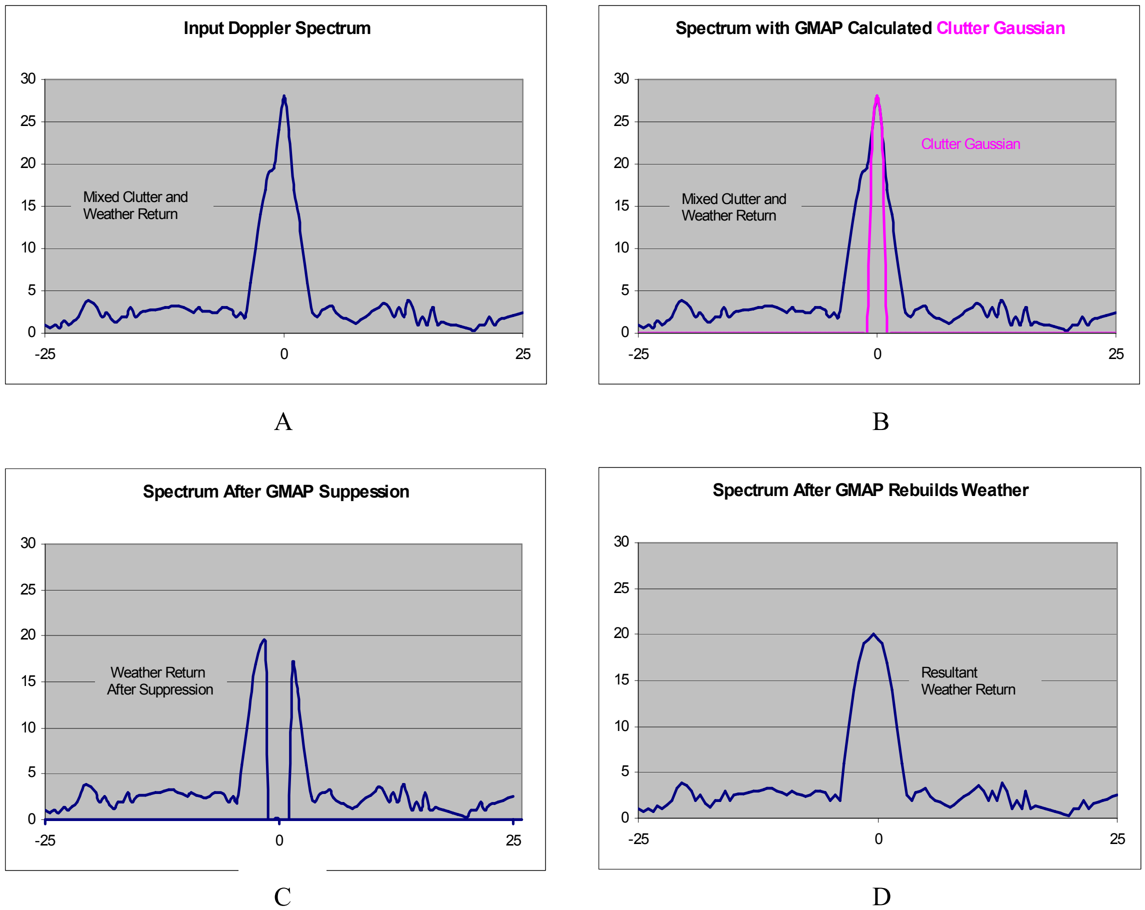

Figure 4. Conceptual Model of GMAP Clutter Filter with Return Centered Over Zero Velocity

A. Input Doppler Spectrum with Mixed Weather and Clutter Return
B. Mixed Weather and Clutter Return Overlaid by GMAP Calculated Gaussian Clutter Spectrum
C. Bimodal Weather Return After Clutter Suppression (this would most resemble the Legacy filtering results)
D. Resultant Rebuilt Frequency Spectrum Used to Calculate the Base Data Estimate

The first step, clutter filtering as described above, is augmented by a second process called "Clutter Censoring".

3. IMPROVED CLUTTER CENSORING

Given that each filter (IIR and GMAP) has inherent limits which cap the amount of power that can be removed (the upper limit on WSR-88D suppression is between 50 and 60 dBZ depending on specific VCP and PRF in use), one would reasonably expect significant residual return displayed in complex or mountainous clutter regimes. However, field investigations have shown that significantly more power is removed from the return than is possible with clutter suppression, IIR or GMAP, alone (Figures 5 and 6).

Both figures are AWIPS 256 data level reflectivity products. Figure 5 shows a radar site with no suppression at all being applied. In the mountainous terrain, returned power is in excess of 75 dBZ and in places, denoted by arrows, it exceeds 80 dBZ. Figure 6 is the same radar site, with maximum suppression applied using the Legacy IIR filter. Note the "cookie cutter" effect where terrain was shown in Figure 6. The light blue echoes are in the clear air regime. It is evident that reflectivity

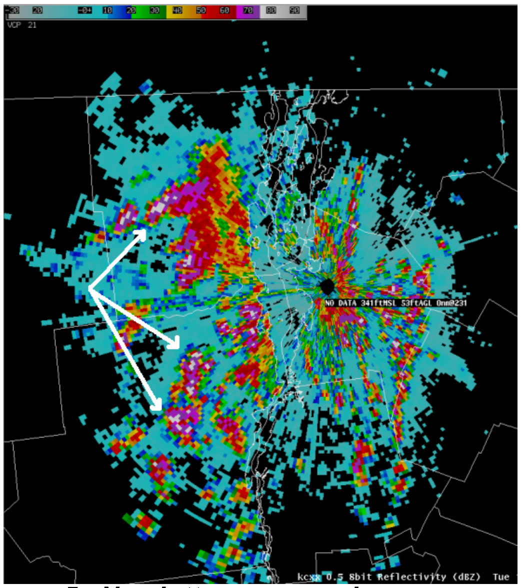

Figure 5. No clutter suppression

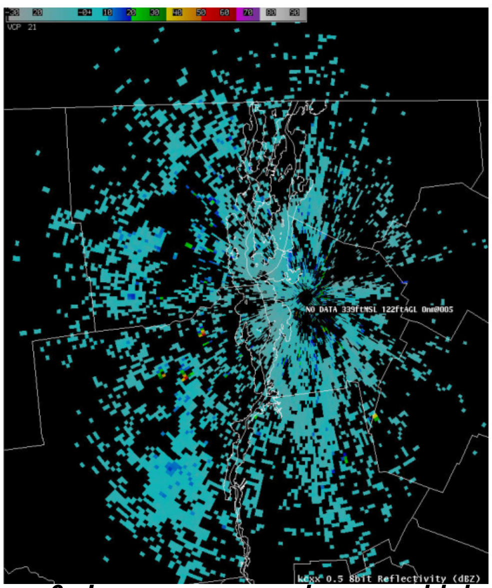

Figure 6. Legacy suppression; map high

data well in excess of 75 dBZ are being removed from the high power terrain return (Ray et al., 2005).

This higher than expected suppression capability is due to a process called “Clutter Censoring”. Legacy signal processing uses “clutter censoring” to remove residual clutter power when high power target returns saturate the clutter filter. This censoring technique is the second step of the WSR-88D clutter suppression process. In an area of identified clutter, power is first removed using the Legacy IIR filter, down to the noise level or between 50-60 dB (Step 1). Then, the remaining noise is threshholded (removed), at a predetermined level, to eliminate any remaining clutter residue (which resembles noise). This censoring step removes unwanted questionable or noisy data from the base moment fields. The combined solution of filtering and censoring is very effective as shown in Figures 5 and 6.

During early testing the ORDA had not yet implemented clutter censoring. This difference in capabilities caused significant differences in the data when the ROC began testing the Legacy and ORDA systems, head-to-head. Figures 7 and 8 show one such ***early*** comparison, revealing the differences in the two respective clutter suppression capabilities.

Both figures are OPUP displays of a radar site, with no clutter filtering invoked except in two zones, to the west of the radar. These zones are filtering the mountain range using Legacy suppression (All Bins, High). The residual clutter is significantly worse using GMAP, although GMAP’s theoretical capabilities surpass those of the Legacy IIR filter. ORDA Engineers realized they needed to implement a censoring solution to achieve the same suppression results as the Legacy system, however, since ORDA performs clutter suppression in the frequency domain instead of the time-series domain they could not simply copy the Legacy process. Through painstaking research, engineering, and testing, the ORDA engineering team learned the intricacies of the Legacy system clutter censoring process.

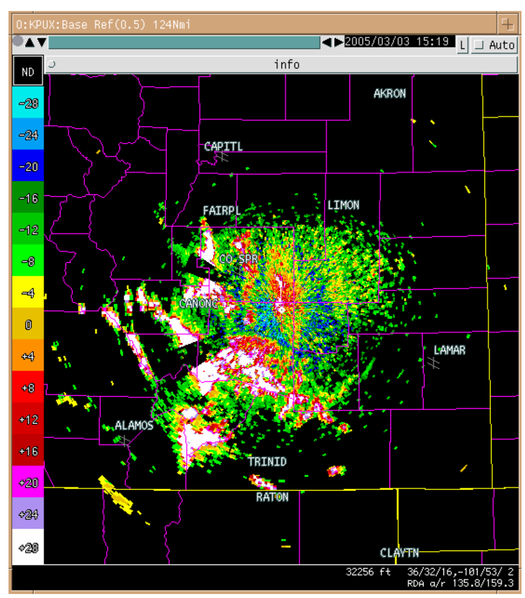

Figure 7. Legacy high suppression in 2 zones

Armed with this knowledge the ORDA engineers began to implement a similar censoring technique in the ORDA signal processing code. The differences in signal processing that originally caused a problem now allowed for the implementation of a dynamically tailored censoring equation. Unlike the Legacy RDA which uses a hard-coded static equation that treats all residual return the same regardless of the remaining power, the ORDA measures the remaining power and calculates a new power factor for each range cell. This dynamic formula censors the residual clutter power with less impact on overlaid meteorological return. As a result, the ORDA team's work to make the GMAP suppress clutter as well as, and with better data quality than the Legacy, was one of their most difficult, yet important tasks.

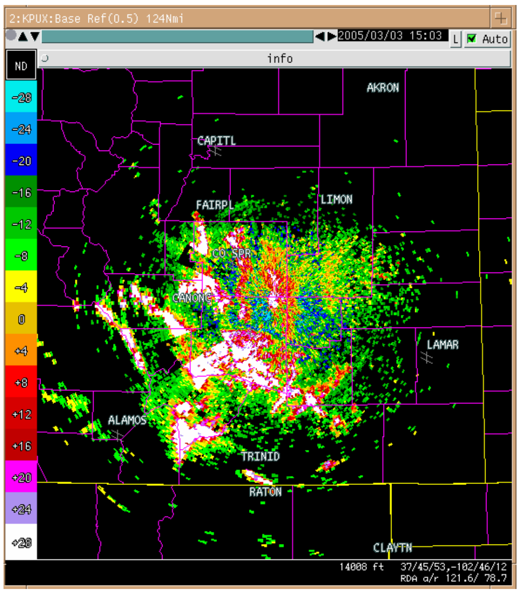

Figure 8. ORDA suppression in 2 zones

Additionally, ORDA also performs censoring of each ¼ km range cell verses the 1 km resolution of the Legacy censoring technique. The higher resolution of the ORDA censoring is quite apparent in Figure 9 (fewer bins of missing data with ORDA clutter censoring).

4. RECENT COMPARISONS BETWEEN LEGACY AND ORDA

A real data example of GMAP's ability to effectively remove clutter return while preserving (rebuilding) the meteorological return is provided in Figure 10. The first reflectivity product (16:15Z) shows the normal ground clutter pattern for this RDA (GMAP clutter filtering OFF). Of interest for this example is the ridgeline that extends from WNW-SW-S of the RDA (just east of (T)uttle and Blanch(ard)) and the return from the local communities (Moore and Norman). In the second image (16:44) GMAP is active (ON), the ridgeline and communities are no longer distinguishable in the

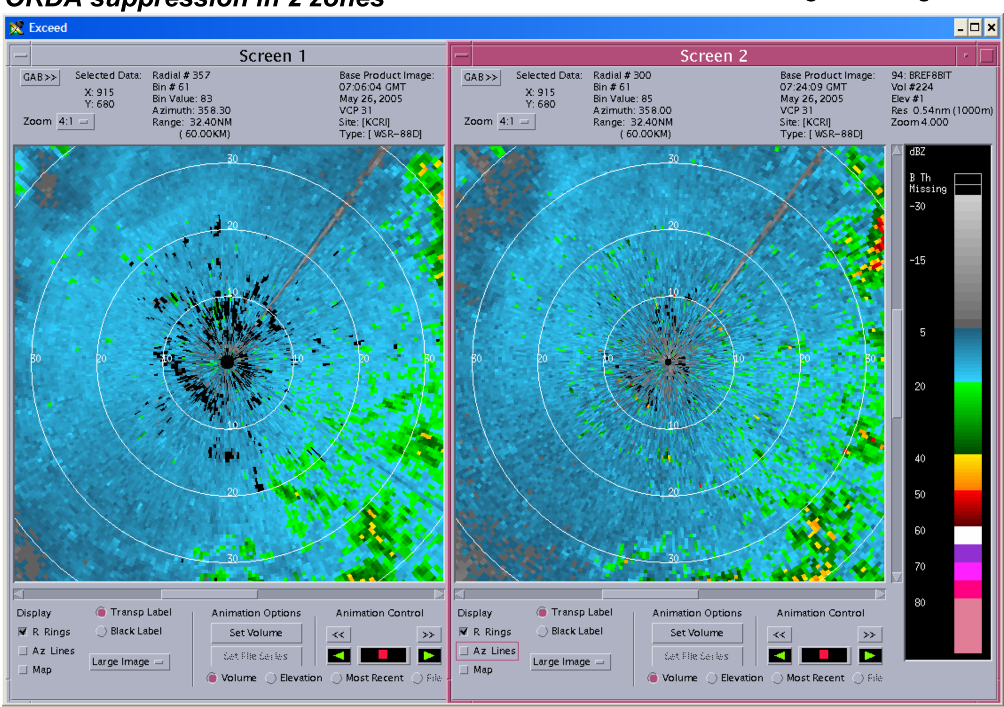

Figure 9. Legacy Clutter Censoring (Left) Verses ORDA Clutter Censoring (Right)

data and a couple of small convective cells are revealed, moving into the local RDA area. These cells continue to move SE (17:14 and 17:38) through the local RDA area with no discernible reduction in reflectivity caused by GMAP.

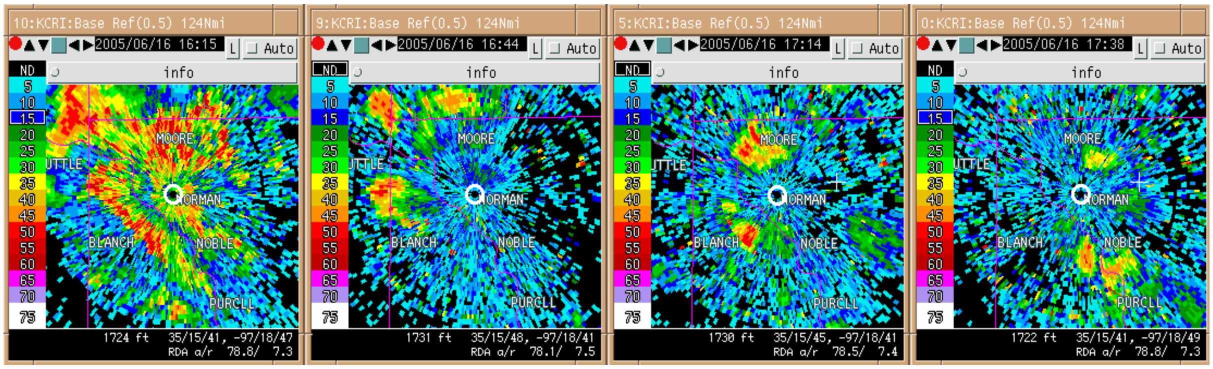

Figure 10. Example Rebuilding Data Through Clutter Contaminated Areas

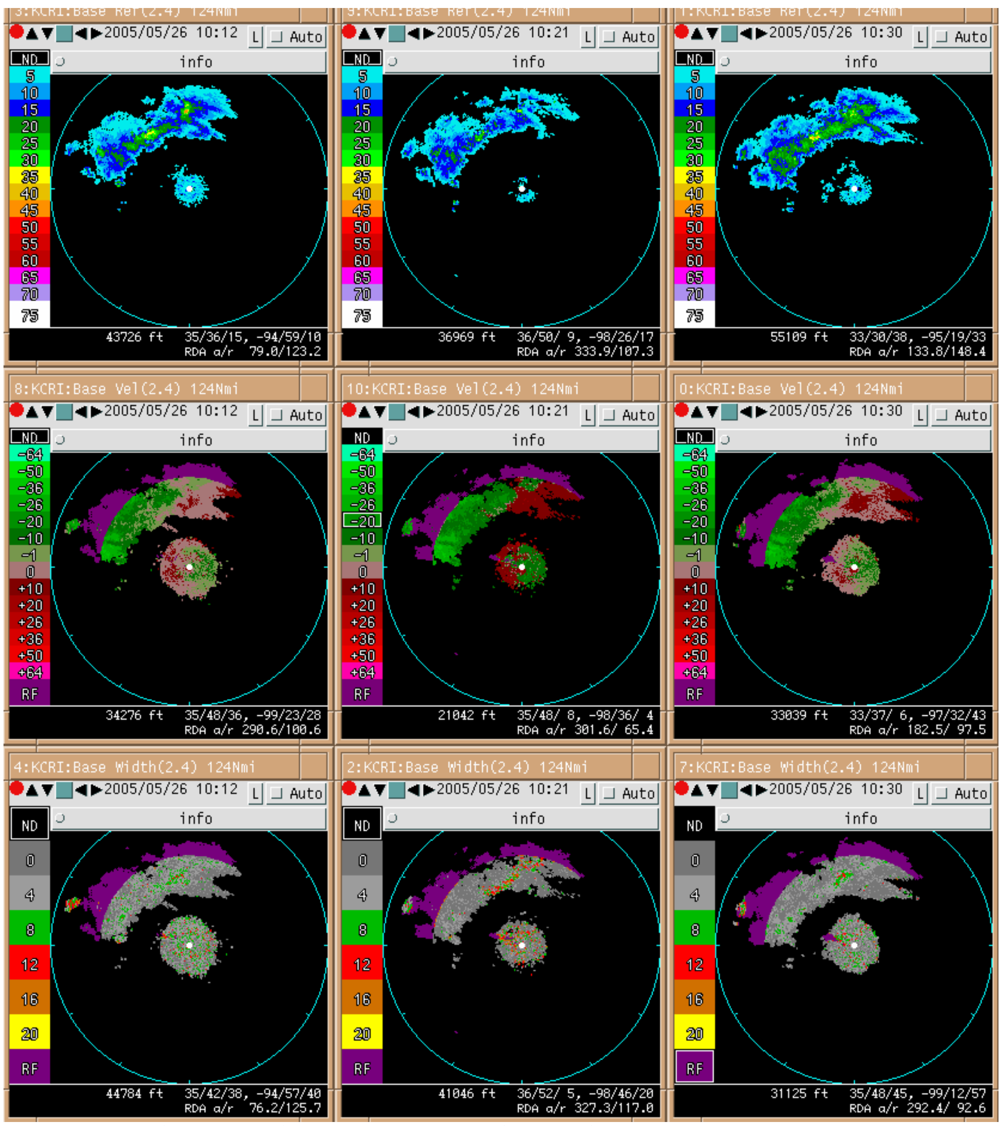

Figure 11. Example of Legacy Clutter Filter and GMAP Clutter Filter Induced Bias

Figure 10 is an example of recovering (rebuilding) meteorological data from bins that contain both clutter and meteorological return as depicted in Figure 4. Another example of the benefit from GMAP processing is the reduction of the clutter filter induced bias from bins that contain ONLY meteorological return. This reduction in clutter filter-induced bias is clearly evident in the data presented in Figure 11 which provides a side-by-side comparison of the three base Doppler moments collected over a 30 minute time span. (Note: the only clutter present at 2.4° elevation for this radar is very close to the RDA.) The left column was collected by the Legacy RDA with clutter filtering OFF. These data, except for the return very close to the RDA, represent the true ambient atmospheric return as seen by radar. The center column was also collected by the Legacy RDA. However, these data were collected with clutter filtering (All Bins, High suppression). The right column was collected with the ORDA with clutter filtering On (GMAP, All Bins).

In comparing these data, notice the reduction in reflectivity returns, the absence of zero velocity data and the "noisier" spectrum width data in the center column (Legacy filter). The GMAP processed data, right column, shows significantly less clutter filter-induced bias (weakened/reduced reflectivity returns, velocities biased away from zero, and broadening of the spectrum widths in weak velocity areas) in the base data estimates.

ORDA clutter suppression implementation will require fewer operator decisions as compared to the Legacy implementation. Operators need only select Bypass Map or All Bins for each region defined. The recommended standard mode of operation for both the Legacy and ORDA is for the clutter suppression application to be controlled by the Bypass Map. This recommendation stems from the desire to address the local ground clutter and limit the clutter filter induced bias in the base data estimates caused by over suppression (refer to Figure 11). The underlying prerequisite for this approach to be valid is the requirement for an up-to-date Bypass Map. For the Legacy RDA, this requirement posed several problems, not the least of which was the time involved in creating a new Bypass Map. Bypass Map generation took 3-4 hours, during which time the radar was off-line and the site technician was occupied at the RDA site.

5. BYPASS MAP IMPROVEMENTS

Unlike the Legacy RDA Bypass Map generation routine that took several seconds to process each radial prior to advancing to the next, the new generation of high speed processors used by the ORDA allow Bypass Map generation while the antenna is in motion. This reduces the Bypass Map generation time from nearly 4 hours (for two elevation segments) to less than 5 minutes per defined elevation segment. Additionally, the technician can graphically monitor the processing on an elevation-by-elevation basis and either accept or abort the process as the bypass map is being created.

There are two other important Bypass Map improvements implemented by the ORDA that will provide cleaner, more accurate base moment estimates.

5.1 *Finer Scale Horizontal Resolution*

Due to the limited processing capacity of the Legacy RDA, there was a need to limit the real-time processing required to maintain the base data stream. Therefore to streamline activation/deactivation of bypass map controlled clutter filtering (on and off), the bypass map was designed to have a horizontal resolution of 1.4° (360° divided by 256) by .54nm. Since limited processing capacity is no longer an issue, the ORDA Bypass Map has a horizontal resolution of 1° by .54nm to match the reflectivity data resolution. Figure 12 clearly shows the differences in the Legacy Bypass map (left) and the ORDA Bypass map (right).

5.2 *Increased Number of Bypass Maps (Vertical Resolution of Elevation Segments)*

The Legacy RDA only supported two Bypass Maps (one for each Elevation Segment): the Elevation Segment 1 Map controlled clutter suppression application for the lowest elevation segment (split cut processing) and the Elevation Segment 2 Map was used for the batch cut elevations up to and including 4.5°. This limitation results in the bypass map from the lowest elevation (worst clutter coverage) in the particular segment to be used for all elevations in that segment, regardless of how the clutter horizon changed with increasing elevation. Although not implemented in the deployment version, the ORDA will support the definition and application of up to 5 elevation segments, each

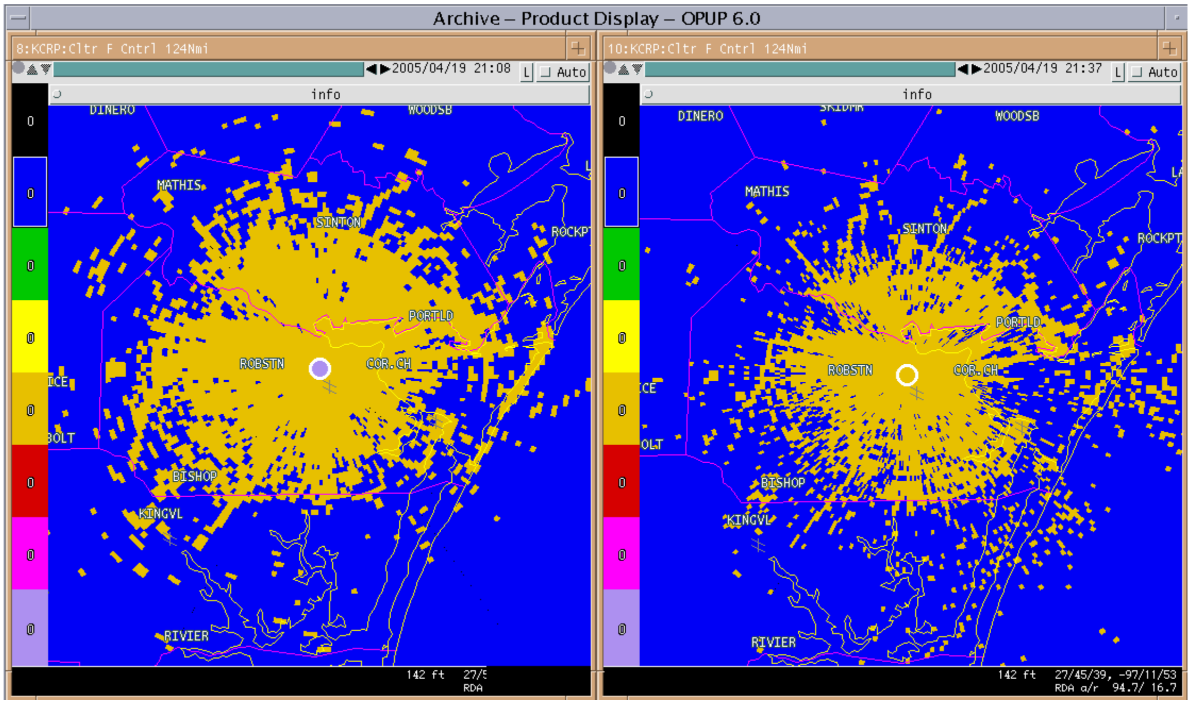

Figure 12. Comparison of Legacy and ORDA Bypass Maps. Note finer structure in the ORDA map (right)

with its own bypass map. These segments, with their respective bypass maps, may be defined and invoked to tailor the application of clutter suppression to the changes in radar horizon with increasing elevation angles. (Note: ORDA will be initially deployed with 2 elevation segments.)

6. ENHANCEMENTS

There are a myriad of new changes to both hardware and software that will be either implemented upon deployment or be made possible by ORDA. As discussed earlier, the capability of the ORDA system to filter and censor strong clutter returns as well as the Legacy system, and then restore legitimate weather data, is but one of the many enhancements operators will see with the new system. Other enhancements the ORDA will make possible include: Dual Polarization; Advanced Range-Velocity Ambiguity Mitigation Techniques; Radial Sampling at ½ degree interval; reflectivity data at ¼ km range resolution; and Doppler processing to the end of the 2nd trip (Saffle et al., 2005).

The hardware changes with ORDA installation are significant. The ORDA replaces the analog receiver/signal processing path with digital hardware that is quieter (less internal system noise), more reliable, and more capable. This allows the system to be more sensitive and have a longer mean time between failure, as well as a wider dynamic range (93-94 dB vice 91-92 dB for Legacy; Sirmans and Urell, 2000). The inclusion of the new digital receiver eliminates the need for the trouble-prone AGC circuitry, DC Bias adjustment and I/Q phase alignment, thereby reducing down time and increasing data quality. Removal of the analog AGC and I/Q detection circuitry increases reliability and eliminates the need for channel alignment (Patel et al., 2005). ORDA bypass map generation, which took several hours with the Legacy system, now takes only minutes which decreases downtime for maintenance. The same can be said for a much simpler and more accurate calibration routine. Further, the new equipment requires only 10 watts, whereas the old system required several hundred (Patel et al., 2005). The result is a decrease in heat output which equates to lower cooling costs and longer component life.

7. SUMMARY

With the preceding discussion of how GMAP will enhance the suppression capability of the WSR-88D, and how other changes will further increase the quality of the data provided to end users and to the national archives, it's interesting to consider how that data will appear subjectively. In other words, can the operators actually see the differences? Fortunately, ROC Engineering has developed the capability to replay Archive Level I (time series) information using the RVP8 signal processor. The playback of time series data allows for selection of relevant weather data and repetitive testing of an algorithm under development. It provides the ability to play recorded data through the processor, then to compare the results with the output of the "Legacy" processing (Rhoton et al, 2005).

The data from which the Figures 13 and 14 were generated, were collected during the same field test as that data shown in Figures 7 and 8.

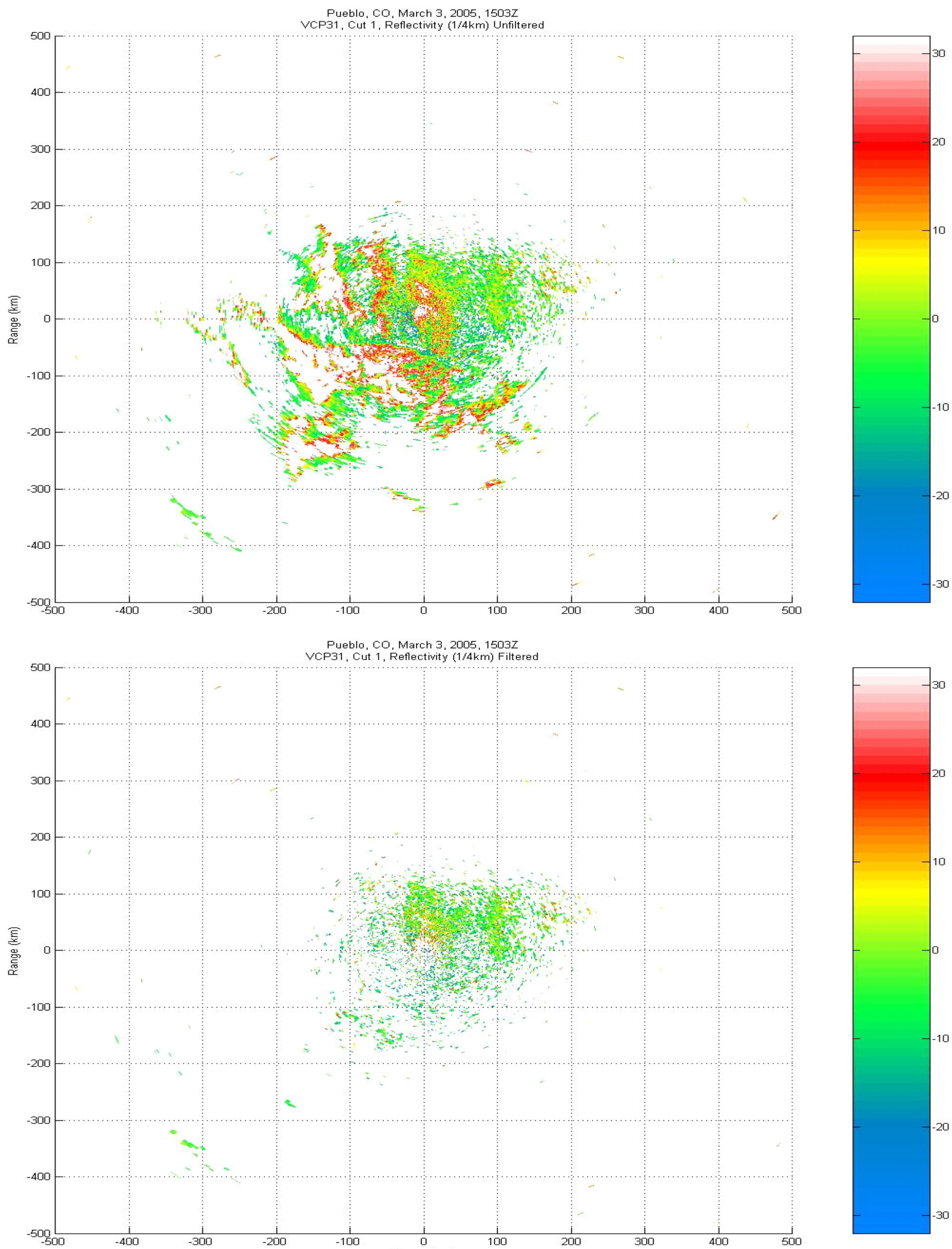

Figure 13. Reflectivity Without and With GMAP Clutter Suppression

The difference is that these data were processed by the ORDA RVP8 signal processor with clutter suppression (GMAP filtering (All Bins) and clutter censoring) invoked. Additionally, the high resolution (¼ km) base reflectivity data was maintained. This provides a good example of what WSR-88D data should look like after deployment of ORDA and implementation of ¼ km resolution reflectivity data processing. Note: Keep in mind that currently base reflectivity data is 1 km (.54 nm) resolution.

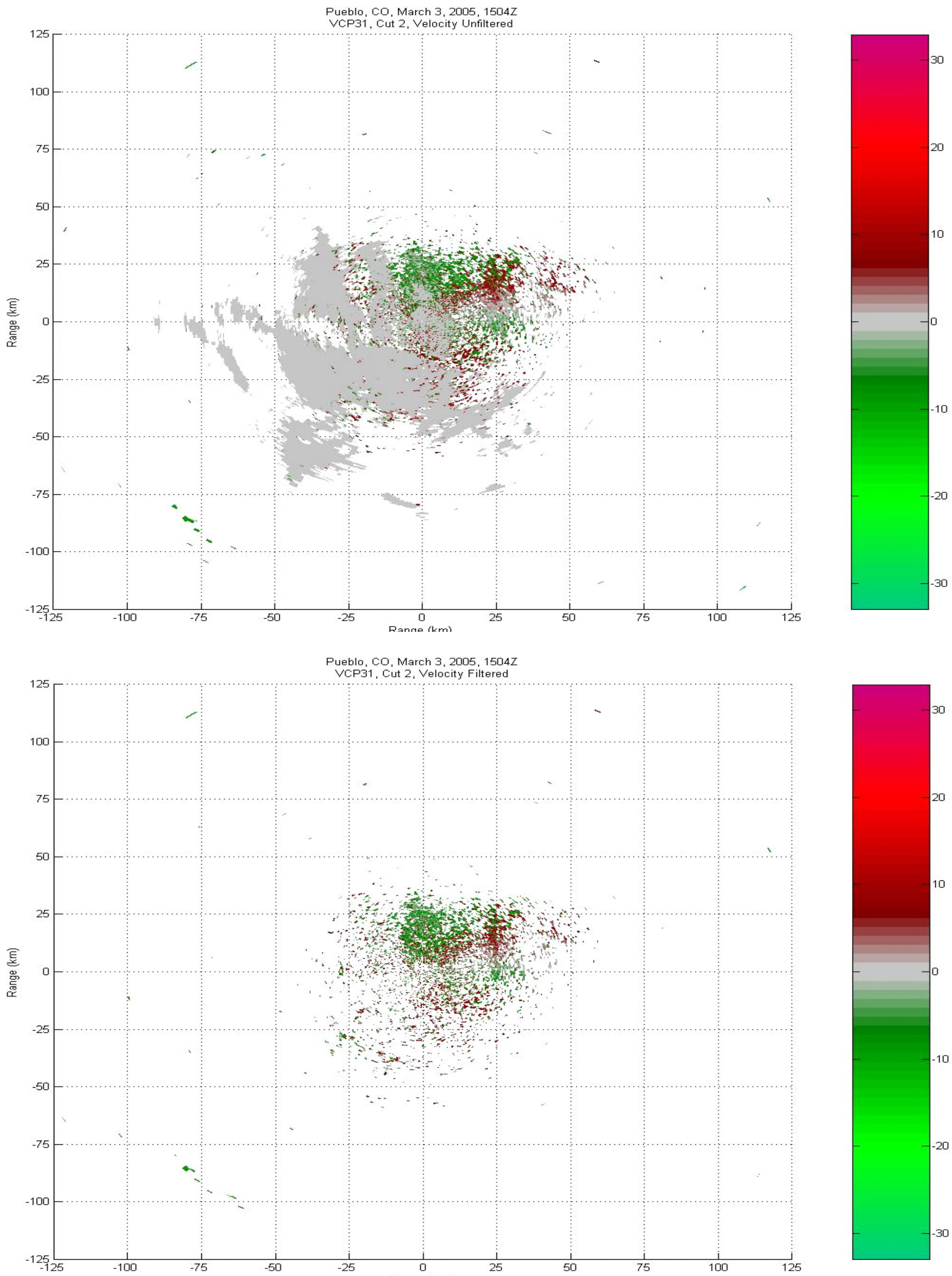

Figure 14. Velocity Data Without and With GMAP Clutter Suppression

In Figure 13, the first image is a base reflectivity with no suppression at all, and it looks very much as one would expect, with the primary difference being its higher resolution. The second image is the same reflectivity data after it was processed by GMAP.

Figure 14 presents the corresponding velocity images. The first image shows just how poor the data is without clutter suppression. The second image is the resultant velocity field after GMAP clutter suppression.

These two figures vividly illustrate the capability of GMAP to retrieve valuable meteorological information for clutter contaminated areas.

8. CONCLUDING REMARKS

The ORDA represents the future for the WSR-88D program. Not only is the ORDA a significant hardware upgrade that will support long-term, future operational enhancements, it also provides immediate data quality improvements (e.g., increased clutter censoring resolution, decreased clutter filter induced bias, etc.,) and improved maintainability. We believe that the ORDA is a momentous leap forward for the WSR-88D operational community.

Note: The views expressed are those of the authors and do not necessarily represent those of the National Weather Service.

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The authors thank the men and women of the Pueblo, CO, Corpus Christi, TX, Norman, OK WFOs as well as Central and Southern Regions for their patience and assistance in field testing ORDA head-to-head with their Legacy systems. We recognize there's a natural hesitancy to allow a team to walk into a perfectly operating radar site and start making changes. The folks at these sites (both Mets and Techs) went far beyond simply allowing entrance. At our request, they tuned their systems, prior to our arrival, provided constant weather briefings, pointed out site-specific, unique radar targets and generally opened their offices to us. This testing would not have been successful without their help, and indeed, major issues such as censoring and inadequate adaptation data entry verification processes would either have not been uncovered, or would have been uncovered too late to fix prior to deployment.

And finally, the authors would also like to thank Jami Boettcher, Don Rinderknecht and Dr. Tim Crum for their invaluable assistance in finalizing this work.

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