P1.4 RADAR OPERATIONS CENTER (ROC) EVALUATION OF NEW SIGNAL PROCESSING TECHNIQUES FOR THE WSR-88D

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INTRODUCTION

The WSR-88D Radar Operations Center (ROC) evaluates all new signal processing techniques for the WSR-88D, assuring compliance with system specifications, and quantifying performance improvements. Recent efforts focused on relative performance measures of spectrum width estimators and new clutter filtering techniques to be implemented in the Open Radar Data Acquisition (ORDA) system planned for deployment in 2005. (Ice, 2004). The ORDA consists of a digital receiver, new PC/Linux based processors, updated network and power management subsystems, and software algorithms under development by the National Weather Service (NWS) Office of Science and Technology (OST), Open Radar Data Acquisition (ORDA) project (Patel, 2004). Most of the emphasis over the past year has been on performance of the new Gaussian Model Adaptive Processing (GMAP) clutter filter technique developed by SIGMET, Inc. for use in the ORDA (Passarelli, 2004).

Radar Operations Center engineers conducted a two phase study on the performance of GMAP. Phase I employed use of signal simulation and statistical analysis of the data resulting from controlled experiments to predict filter performance in the expected meteorological environment. Phase II expanded the analysis through use of actual radar data. Detailed reports of both efforts are available on the ROC web site at http://www.roc.noaa.gov/eng/RVP8Evalreports.asp. This paper is a summary of the Phase II evaluation.

EVALUATION METHODS

The engineering team uses several methods for analyzing system performance, using both quantitative statistical analysis and qualitative review. Phase I focused entirely on the use of a signal simulator based on techniques used by early investigators researching velocity and spectrum width estimators (Sirmans and Bumgarner, 1975). The simulator allowed engineers to specify weather, noise, and clutter signal parameters, to permit flexible performance analysis under expected conditions. The evaluation team used this technique to test performance of the new GMAP algorithm over the entire range of WSR-88D specifications. Simulation is a useful technique for determining performance bounds, but is less useful for quantifying effects on actual radar data. This is because real weather signals can exhibit behavior outside the boundaries of ideal models.

Evaluating signal processing algorithm performance on real radar data presents several challenges. There are significant technical issues with data collection. For maximum flexibility, research teams require radar receiver time series data. This is the digitized output of the radar receiver, and consists of the raw in-phase and quadrature-phase (I,Q) pairs representing the summation of all amplitude and phase information captured in the radar resolution volume at the instant of sampling. Time series represents the most useful form of radar data, especially when paired with flexible playback schemes which allow investigators to input the time series into the signal processor while varying applicable control parameters. In this fashion, researchers can process identical sets of meteorological returns through various algorithms for clutter filtering and moment estimation, while having complete control over relevant parameters.

Depending on antenna scan rate and the pulse repetition frequency (PRF) of the radar transmitter, anywhere from 16 to 278 I,Q pairs are used to produce the individual moment estimates. Time series data files are thus quite large and have only been used in a limited capacity in the past. However, recent advances in mass storage and processor performance have permitted development of robust time series recording methods. Earlier time series recording efforts conducted by the ROC and the National Center for Atmospheric Research (NCAR), while generally successful, were somewhat limited due to the cumbersome nature of the equipment and the complex interface to the legacy WSR-88D signal processor. With the advent of the Open RDA architecture, the National Severe Storms Laboratory (NSSL), the ROC, and SIGMET have produced quite usable time series recording systems for the WSR-88D.

For this investigation, ROC engineers focused on processing time series data collected from WSR-88D

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radars using several means described below. They used a playback mechanism developed by the ROC Engineering Branch which is based on a modified major mode of the SIGMET RVP8 signal processor. This mode permits ingesting of time series data into the RVP8 while allowing system parameters to be adjusted. Engineers were able to set up the GMAP clutter filters and control relevant system parameters such as calibration constants, noise levels, thresholds, number of samples per estimate, and output ray processing.

The evaluation team obtained time series data from NSSL originating with the Research Radar Data Acquisition (RRDA) system which is a modified WSR-88D used for advanced research. NSSL provided several data sets collected in support of other projects, including the development of staggered PRT for range-velocity ambiguity reduction (Torres, 2003). The NSSL team maintains a flexible system capable of operating the RRDA with either a modern distributed system for prototyping techniques, or the legacy WSR-88D processors. The NSSL team also has incorporated a SIGMET RVP8 into the RRDA. NSSL supplied data sets in the RRDA time series format for several meteorological cases. The ROC team analyzed seven diverse cases using the Research Radar Analysis Tool (RRAT) supplied by NSSL (Priegnitz, 2004) and selected two for detailed study. The cases consisted of a stratiform rain event on February 24, 2004 and the Oklahoma tornado outbreak of May 8 – 9, 2003. Figure 1 is a representative sample of data provided for the May 8, 2003 tornado displayed using the RRAT. Additionally, NSSL conducted some special clear air studies for the ROC team.

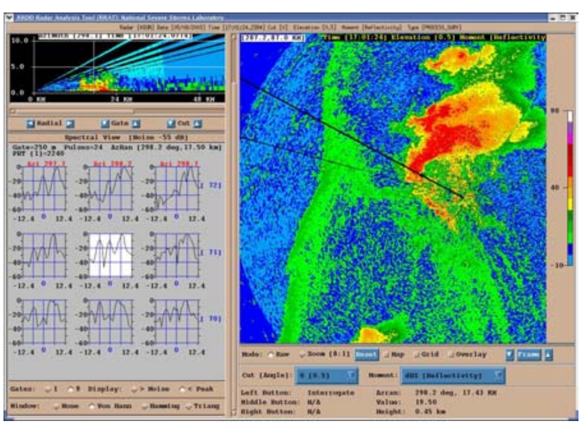

Figure 1 - RRAT Analysis Example

The ROC team also collected time series data on the ORDA production prototype radar (KJIM) using a utility developed by ROC Engineering. The Level 1 Record and Playback (L1RP) program captures the IQ data from the RVP8 processor via the local network using the application programming interface supplied by SIGMET. L1RP also features a playback in an RVP8 major mode. This was the major playback mechanism the team used for converting the time series data sets into moment outputs. ROC engineers also developed a utility for converting NSSL RRDA time series data into L1RP format for subsequent playback.

A limited amount of data collected using the legacy system was also obtained from NCAR. A legacy data set containing anomalously propagated (AP) clutter collected in Memphis TN in the summer of 1997 provided an initial case for evaluating GMAP performance in AP clutter. The ROC team developed a utility for converting this data set into L1RP format as well to enable playback.

Results of the various playback outputs were viewed using the Open Radar Product Generator (ORPG) base data display and a MATLAB display utility. The team also used a number of MATLAB routines to conduct statistical analysis. Tools to convert WSR-88D level 2 base products were also developed by ROC software engineers in support of this program. With these tools, moment data from any WSR-88D can be analyzed statistically with MATLAB.

QUALITATIVE IMAGE ANALYSIS

Several examples of radar data images are presented here to illustrate clutter filter performance.

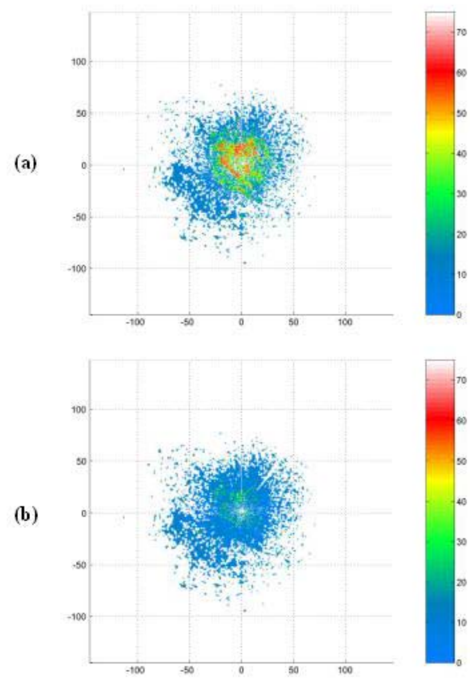

Figure 2 - GMAP Clutter Suppression - April 17, 2004

Figure 2 depicts reflectivity fields containing clutter (a) and the result from processing the same time series data through the GMAP clutter filter (b) for a case of weak meteorological signal. This data is from the KJIM ORDA located in Norman OK. As seen in this case, the GMAP filter significantly reduces the ground clutter while adequately reconstructing the weak signals.

Figure 3 is a similar analysis of a case with a mix of weak signal, clutter, and convection observed on April 9, 2004 by the KJIM ORDA system. This shows a large scale reflectivity image, obtained by processing time series data through an RVP8 and then displaying with MATLAB. Figure 3(a) is the unfiltered reflectivity while Figure 3(b) shows the output result from applying the GMAP clutter filter over the entire region.

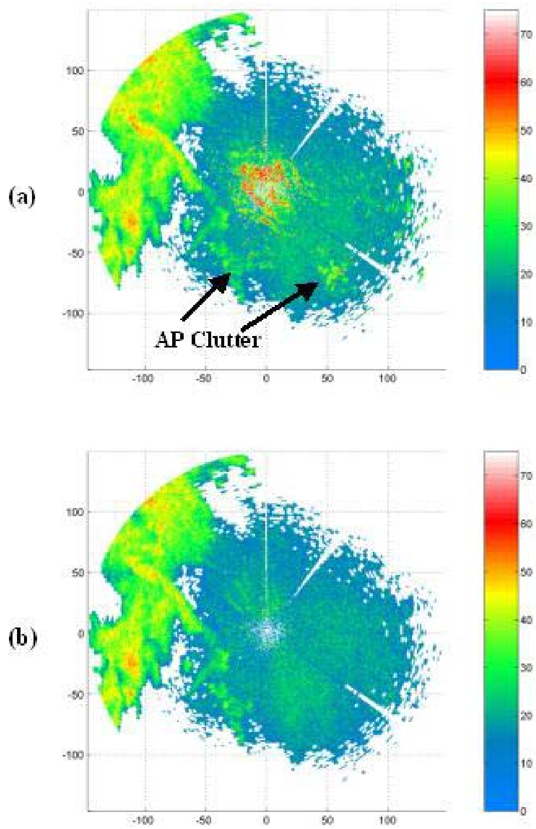

Figure 3 - Suppression - Convective Case, April 9, 2004

Note that in Figure 3, the close-in ground clutter is eliminated by the filter, while additional clutter regions are reduced as well, most notably to the south east of the radar. This appears to have been a case of AP clutter that was adequately handled by the GMAP filters. While obvious clutter regions have been reduced significantly, the valid weather returns are not appreciably affected.

Figure 4 depicts a close-up view of the reflectivity featuring the small AP clutter patch south east of Norman OK. Note that in addition to the obvious larger clutter patch, there are a number of smaller clutter areas seen in Figure 4(a). These are easily filtered by GMAP and the reflectivity estimates appear to be adequately recovered in these areas. The analysis that these areas are AP clutter is confirmed by the velocity images of Figure 5. The areas of suspected AP clutter in Figure 3(a) and 4(a) can be seen to correspond to locations where the velocity estimates have a zero mean as expected for ground clutter returns.

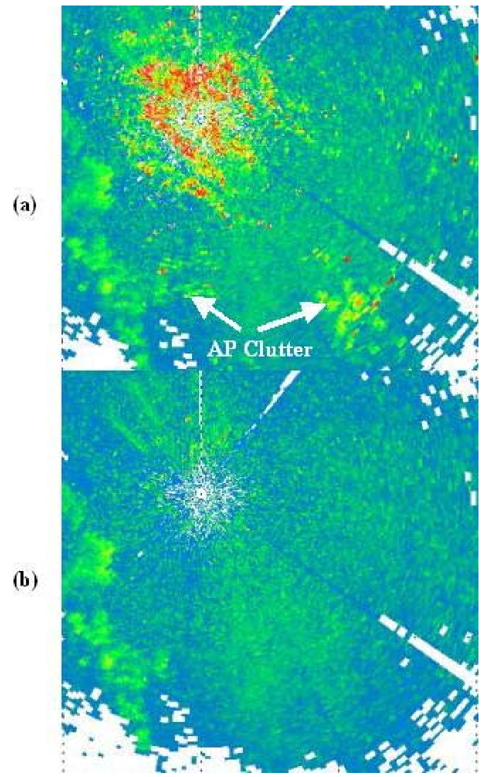

Figure 4 - Close-up AP Clutter Patch

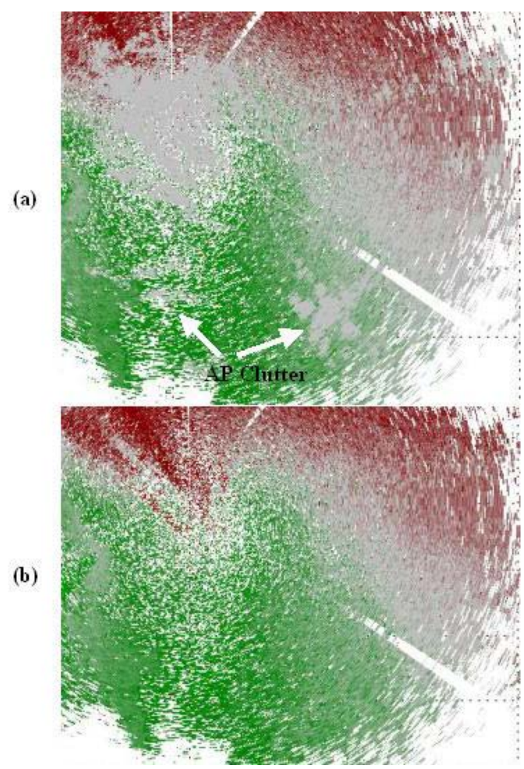

Figure 5 - Velocity Image, April 9, 2004

The images of Figure 5 also demonstrate GMAP filter's ability to recover velocity estimates in the presence of clutter.

Figure 6 illustrates the one legacy time series case processed by the evaluation team. This display is of reflectivity data obtained from the RVP8 processor with time series data collected on the Memphis TN radar (KNQA) in the summer of 1997. It shows a wide spread area of AP clutter stretching from the radar outwards to the east and south east with some weaker clutter to the north east seen in Figure 6(a),

(a)

(b)

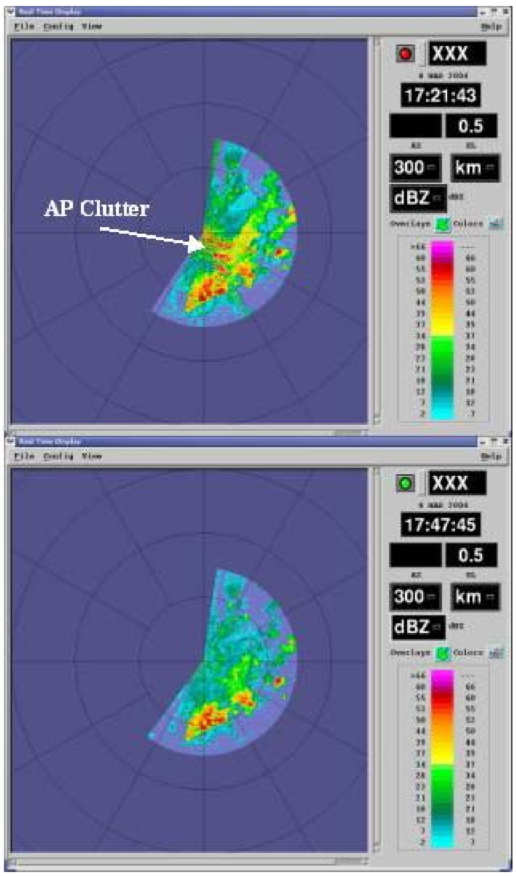

Figure 6 - KNQA AP Clutter Case 1997

Figure 6(b) shows the same data processed through the GMAP filter with the AP clutter reduced and the reflectivity estimates recovered. The missing wedge of data is the result of hardware storage limitations of the original time series recorder in use at the time. The research team limited recording to the sector of interest.

QUANTITATIVE STATISTICAL ANALYSIS

Detailed quantitative analysis was performed on three specific cases. Case 1 consisted of clutter with weak clear air return. Case 2 was a moderate meteorological signal (stratiform rain) with clutter, and Case 3 consisted of a mix of convective and weak signals including clutter. In addition to detailed analysis of the above cases, the ROC team evaluated the performance of the GMAP filter with various input parameters, most notably the selection of the initial (expected) value of the clutter signal spectrum width, or "seed width" which is the only input parameter needed to set up the GMAP filters.

In order to determine clutter suppression levels for reflectivity data, the team performed regression analysis of filtered versus unfiltered results. Figure 7 shows a regression scatter gram of GMAP filtered reflectivity estimates versus the non-filtered results for the same input time series taken on April 17, 2004 (see Figure 2 for the reflectivity images). Each dot on the graph represents a pairing of reflectivity estimate outputs, one filtered, one not, for each range gate in the data set. The data is limited to a range of 1 to 35 km, encompassing most of the observed ground clutter.

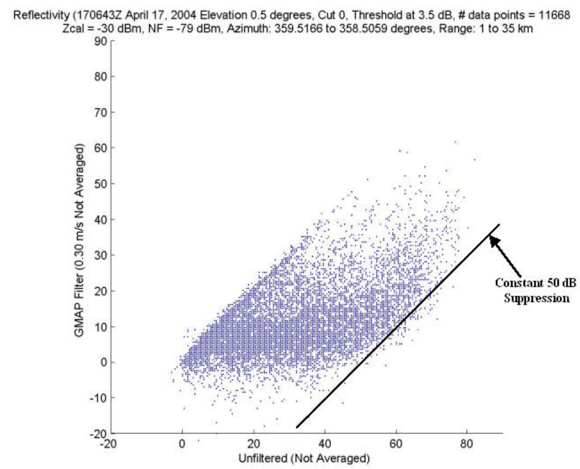

Figure 7 - Reflectivity Scatter gram - April 17, 2004

The scatter gram depicts the amount of difference between the two processes. If the two processes produce identical results, then all data points would be concentrated along a line of unity slope passing through the zero origin. This would be the case for data containing no clutter (no filter effect) with no bias on the remaining weather signals. The display for a data set containing pure clutter of various magnitudes would show all data points below the unity slope line. In this case, the data set contains a mix of clutter and weak meteorological returns. Data points containing mostly weather signal can be seen clustered along the unity slope line while those containing mostly clutter are suppressed below the line and moved down and to the right. The black line represents a constant difference (or suppression) of 50 dB. As can be seen, some data points are suppressed below 50 dB indicating the GMAP filter is capable of suppressing clutter of this magnitude.

The team also analyzed bias effects on moment estimates resulting from use of the GMAP filter. Figure 8 is an analysis of the bias effects of clutter filtering on velocity estimates. It is also a regression scatter gram comparing velocity estimates from both the unfiltered and filtered process. This data is taken from a region of fairly strong weather signal in the April 9, 2004 case (Figure 3) and depicts how the GMAP filter acts on signals containing predominately weather returns. As can be seen, there is a slight (close to 1.0 ms^{-1}) bias effect for estimates close to the zero mean. This is well within the WSR-88D specification which calls for bias effects to be less than 2 ms^{-1} for clutter filtered velocity estimates.

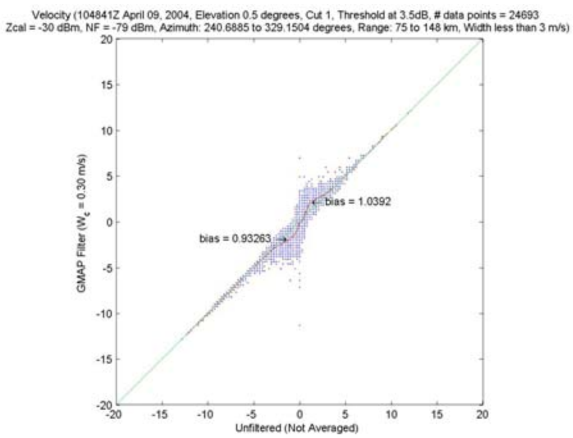

Figure 8 - Velocity Bias, Moderate Weather Returns

While there is no specific bias requirement for reflectivity estimates produced by a clutter filter process, the engineering team evaluated this effect. Figure 9 is a sample of the reflectivity bias analysis. It is a plot of all reflectivity values sorted by the associated velocity. This is for the April 17, 2004 case of weak meteorological return in the presence of clutter.

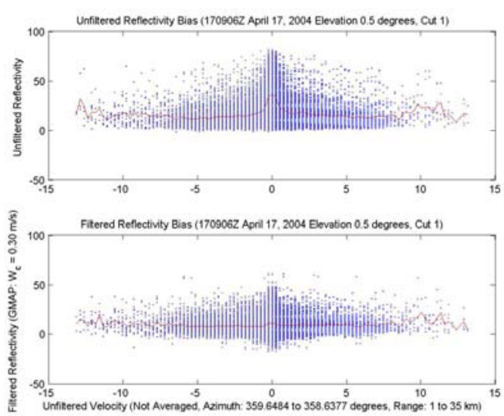

Figure 9 - Reflectivity Bias, Weak Meteorological Signal

In Figure 9, the top graph is for the unfiltered data and the lower graph is the same data set, passed through the GMAP filter. The large spread of data points in the center (0 mean velocity) are primarily from ground clutter. The red line is the average of all the reflectivity estimates as a function of velocity. As can be seen, the mean of reflectivity is high in the clutter region clustered around zero velocity. In the filtered output, the mean values are much lower around the zero velocity center. This is a demonstration of the GMAP process which suppresses clutter values while replacing the removed clutter signal power with a reconstructed estimate. Note that the reconstruction process follows an expected Gaussian model, which is not always how the weather signals behave. This introduces a slight bias and an increase in standard deviation. This is seen in Figure 9 on the filtered graph as a slight positive rise around 0 mean velocity and a larger spread of reflectivity values.

For this case, the reflectivity bias is close to the post filter/corrected goal of 2 dB for the WSR-88D. The team noted several cases where this goal was not met. However, this is not considered a system requirement and no corresponding requirement was in place for the legacy notch filters. The team analyzed standard deviations for all cases and determined that GMAP meets the standard deviation requirements of 2 dB for reflectivity and 2 ms^{-1} for velocity and spectrum width estimates.

LEGACY CLUTTER FILTER COMPARISON

The ROC team compared GMAP performance with the legacy 5-pole elliptic with the help of NSSL. The NSSL team has the capability of replaying RRDA time series data through their signal processor algorithms which implement the legacy design. The team obtained legacy processed data for the May 8, 2003 tornado case and the February 24, 2004 stratiform rain case.

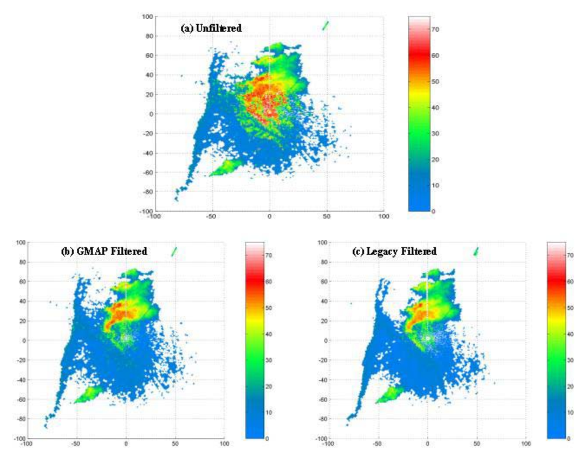

Figure 10 - May 8, 2003 Filter Comparison, Reflectivity

Figure 10 shows the results of the analysis for the May 8, 2003 Oklahoma City tornado. The top image is the unfiltered reflectivity as processed through the RVP8. Note that the tornadic storm directly to the north of the radar is nearly obscured by the ground clutter. The lower left image is the same data processed through the GMAP filter. The lower right image is the data set supplied by NSSL as processed through the legacy filter with maximum suppression invoked. Both filters recover the reflectivity data associated with the storm and the hook echo can be seen clearly. Close examination reveals that the legacy filter leaves slightly more clutter residue, but performance is essentially the same.

Figure 11 is the corresponding set of images for the velocity estimates. Note that in the unfiltered image, the storm rotation is obscured, but that both filtered images reveal the strong rotation. Outputs are essentially the same for both filters. The team observed similar results with the February 24, 2004 stratiform rain case data set. GMAP performs as well as the legacy and in some cases it exhibits higher suppression. Bias performance is generally better in areas containing signal alone as expected with the signal coefficient reconstruction process employed by GMAP.

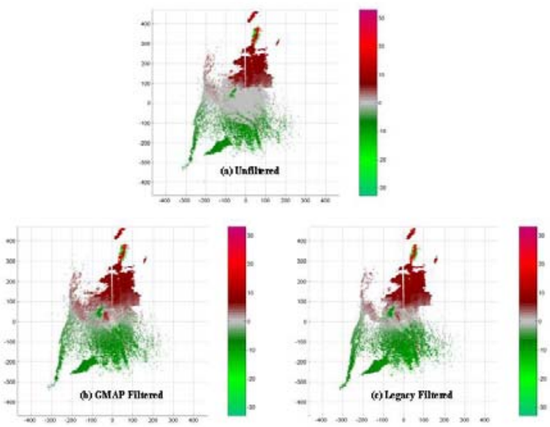

Figure 11 - May 8, 2004 Filter Comparison, Velocity

FUTURE WORK

The ROC engineering team is working on improvements to the time series recording and play back process (Rhoton, 2005). ROC Engineering will be coordinating with SIGMET and the Open RDA team to produce a robust system compatible with the RVP8 commercial interfaces and the ORDA software. ROC also plans to continue evaluating new science techniques for the WSR-88D, with near term plans to evaluate Super Resolution (Warde, 2005) and the SZ2 Phase Coding algorithm (Saxion, 2005)

ACKNOWLEGEMENTS

The evaluation team would like to acknowledge the support provided by NSSL. In particular, the team led by Mike Jain was especially helpful. Dan Suppes provided a great many time series data sets. Dave Preignitz graciously supplied the RRAT analysis software and helped the ROC team with installation and user interface issues. Eddie Forren provided legacy processed data. The engineering team led by Allen Zahrai developed the RRDA test bed and time series recording systems which made it possible to obtain such a wide variety of weather cases for the study.

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