P1.8 RADAR OPERATIONS CENTER (ROC) EVALUATION OF PROPOSED SUPER RESOLUTION TECHNIQUES FOR THE WSR-88D

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INTRODUCTION

With the deployment of the Open Radar Data Acquisition (RDA) system, many new science enhancements can be incorporated into the WSR-88D radar that take advantage of the SIGMET Radar Video Processor (RVP8) processing power and existing algorithms. The Radar Operations Center (ROC) Engineering branch is responsible for ensuring that implementation of these new signal processing algorithms meet WSR-88D system specifications. One of the proposed enhancements to the WSR-88D RDA is Super Resolution. It has been demonstrated through simulation and real data studies (Wood, 2001; Brown, 2003) that high-resolution products (quarter kilometer with half degree beam width) can increase detection range of mesocyclonic and tornadic activity.

ROC is considering a phased approach in the implementation of Super Resolution into the Open RDA system. The phased approach will produce several modifications to existing WSR-88D products. The first enhancement will increase the range resolution of the reflectivity moment from a one-kilometer product to a quarter-kilometer product. The second enhancement will be in the collection of radials at half-degree resolution. Although the collection will be at half-degree radials, the collection activity will be across a full degree (overlapping radials). The National Severe Storms Lab has shown that these overlapped radials will provide a 16 percent increase in detection of tornado vortex signatures over the legacy equipment (Brown, 2004). This enhancement will increase the resolution of the reflectivity product by eight and the Doppler products (velocity and spectrum width) by two. The third enhancement furthers the detection range by 50 percent over legacy by narrowing the beam width to half-degree which fully implements high-resolution products with quarter-kilometer and half-degree beam width (Brown, 2004).

This paper describes ROC Engineering Branch development of techniques that allow the RVP8 to produce base data in the proposed high resolution formats. Preliminary results of simulations and playback of archived level I data will be presented.

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EVALUATION METHODS

The evaluation team expanded their analysis of the WSR-88D Open RDA system signal processing performance (Ice, 2004) to include lower sample-sizes expected with the half-degree beam widths associated with the final phase of Super Resolution implementation. The SIGMET Ascope utility along with the SIGMET simulator was used to simulate the meteorological characteristics across the Nyquist interval for several clutter-to-signal (CSR) and signal-to-noise (SNR) inputs.

Additionally, the team relied on the use of recorded weather events and a ROC created playback capability in an archive Level I Record and Playback (L1RP) format (Rhoton, 2005) to evaluate the proposed Super Resolution products. Archive level I data provided by the National Severe Storms Laboratory (NSSL) and many of the utilities created for the phase II Gaussian Model Adaptive Process (GMAP) evaluation (Ice, 2005) were reused during this evaluation. During phase II of the GMAP evaluation, team members, with assistance from NSSL, created a utility to convert the NSSL formatted level I products into a L1RP format to playback on the RVP8. For an explanation of the GMAP filter see Passarelli, 2004.

With the use of a user defined FFT major mode and the SIGMET IRIS utility running on the Radar Control Processor (RCP8), the team was able to playback L1RP format level I data on the RVP8. We adjusted the following Open RDA system parameters to create the different Super Resolution products: sample sizes, “minimum freerunning ray holdoff,” scan resolution, and windowing. These parameters are accessible in different SIGMET utilities. The SIGMET IRIS utility provided the capability to control the coherent processing interval (CPI) by adjustment of the sample size, and adjustment of the azimuth resolution by adjusting the scan resolution. The SIGMET DSPX utility provided control of the “minimum freerunning ray holdoff” which allowed testing overlapping radials. The SIGMET Setup utility provided selection of the power spectra window type. Only the Blackman window was tested during this evaluation because of the GMAP filter was found to work best with this windowing scheme (Ice, 2004). The Open RDA system configures the RVP8 to process radials on fixed boundaries with variable CPI (spacial processing); for ease of setup, we used the legacy style with varying radial boundaries and a fixed CPI (temporal processing) for this evaluation. The output of the IRIS utility is a level II “RAW” file that contains selected base moments at quarter-kilometer range bins. For this evaluation, 16-bit reflectivity, velocity and spectrum width moments were selected for output. Since none of the Super Resolution products are in legacy level II format, the team created a utility to ingest the SIGMET formatted RAW files into MATLAB for further analysis and display.

EVALUATION PRELIMINARY RESULTS

(a) Simulations

For the simulation phase, our testing focused on how the performance of the Open RDA met NEXRAD technical requirements (NTR) for clutter filtering (e.g. Ice, 2004.). To meet the NTR, mean radial velocity bias in the presence of 30 dB CSR with a 20 dB SNR cannot exceed 2 ms^{-1}. The tables below show the clutter filtering performance that can be expected with various sampling rates (NS). The first column is the normalized velocity where V is the velocity of the meteorology and V_n is the Nyquist velocity. The velocity bias is under the column Vbias and the standard deviation of the velocity is under the column SD[V].

Table 1 shows the clutter filtering velocity performance for a typical Open RDA Volume Coverage Pattern (VCP) Doppler product with a one-degree beam width. The one-degree beam width products would be the same as the first two proposed Super Resolution enhancements: quarter-kilometer with one-degree resolution and quarter-kilometer with half-degree resolution/one-degree beam width (overlapping radials).

Table 1, Doppler–Velocity; NS = 32, SNR = 10 dB

	CSR= 10 dB		CSR = 30 dB		CSR = 50 dB	
V/V_n	Vbias	SD[V]	Vbias	SD[V]	Vbias	SD[V]
0.0	-0.01	2.12	-0.02	2.20	0.01	2.14
0.1	0.80	2.20	0.80	2.28	1.96	2.30
0.2	1.18	1.98	1.05	2.04	-0.43	2.30
0.3	0.51	2.01	0.51	2.04	-1.34	2.60
0.4	-0.03	1.96	0.01	2.01	-1.88	2.68
0.5	-0.07	1.88	-0.16	1.93	-1.93	2.95
0.6	-0.08	1.69	0.01	1.68	-1.61	2.95
0.7	0.05	1.58	0.02	1.66	-1.13	2.68
0.8	0.02	1.77	0.01	1.77	-0.86	2.95

Table 2 shows the clutter filtering performance for a typical Super Resolution VCP Doppler product with a half-degree beam width. Both of these examples show the RVP8 clutter filtering process can meet the NTR velocity bias within the typical Super Resolution VCP Doppler product.

Table 3 is the reflectivity bias exhibited on the same weather characteristics as above. Although not stated in the NTR (this work was an enhancement to hydrology and undertaken much later circa 1990), the post filter reflectivity bias correction algorithm has a goal of correction uncertainty of less than about 2 dB for a one-kilometer range resolution. As stated earlier, the Super Resolution reflectivity products will be at 250 meter range resolution. This will cause the goal of the corrected uncertainty to increase to about 4 dB (Sirmans, 1993). The increase in uncertainty caused by the increase in range resolution may be mitigated by the inclusion of Whitening and Over-Sampling techniques (e.g.: Torres, 2001 and Torres and Zrnic, 2001).

Table 2, Doppler–Velocity; NS = 16, SNR = 10 dB

	CSR= 10 dB		CSR = 30 dB		CSR = 50 dB	
V/V_n	Vbias	SD[V]	Vbias	SD[V]	Vbias	SD[V]
0.0	0.00	0.30	0.00	0.31	-0.01	0.44
0.1	-0.11	0.23	-0.11	0.25	-0.05	0.40
0.2	-0.12	0.16	-0.13	0.17	-0.06	0.30
0.3	-0.08	0.12	-0.08	0.13	-0.06	0.21
0.4	-0.03	0.12	-0.04	0.11	-0.04	0.16
0.5	0.00	0.12	0.00	0.12	0.00	0.15
0.6	0.01	0.12	0.01	0.12	0.02	0.15
0.7	0.02	0.12	0.01	0.12	0.03	0.14
0.8	0.02	0.19	0.03	0.22	0.04	0.22

Table 3, Doppler–Reflectivity; NS = 32, SNR = 10 dB

	CSR= 10 dB		CSR = 30 dB		CSR = 50 dB	
V/V_n	Pbias	SD[P]	Pbias	SD[P]	Pbias	SD[P]
0.0	-1.12	3.42	-1.12	3.75	-1.32	3.55
0.1	-1.78	3.34	-1.73	3.83	-1.28	3.79
0.2	-1.74	3.07	-1.62	3.16	-0.33	3.32
0.3	-0.88	2.60	-0.91	2.74	-0.40	2.92
0.4	-0.56	2.43	-0.55	2.54	0.74	2.41
0.5	-0.55	2.30	-0.51	2.32	0.54	2.13
0.6	-0.54	2.30	-0.56	2.28	0.21	2.08
0.7	-0.57	2.27	-0.54	2.25	0.05	2.13
0.8	-0.60	2.31	-0.56	2.26	-0.05	2.07

In Table 4, we see the post filter reflectivity bias increases beyond the goal of 4 dB for low velocities with a typical Super Resolution VCP Doppler product with a half-degree beam width. The unambiguous Nyquist velocity for this data was about 26.8 ms^{-1} which indicate that velocities below about 5.4 ms^{-1} are quantitatively unusable in the half-degree beam width Super Resolution products. Although not shown, similar biases were observed with the simulator using a 30 dB SNR which indicates that performance at 20 dB SNR would be the same as presented.

Table 4, Doppler–Reflectivity; NS = 16, SNR = 10 dB

	CSR= 10 dB		CSR = 30 dB		CSR = 50 dB	
V/V_n	Pbias	SD[P]	Pbias	SD[P]	Pbias	SD[P]
0.0	-11.19	12.34	-11.59	12.12	-15.91	13.03
0.1	-9.18	10.70	-10.11	10.92	-12.60	11.22
0.2	-6.23	7.69	-6.73	8.16	-8.47	9.25
0.3	-3.46	5.40	-3.69	5.70	-4.80	6.27
0.4	-2.00	4.17	-2.05	4.39	-2.51	4.84
0.5	-1.22	3.61	-1.19	3.72	-1.20	4.11
0.6	-0.98	3.43	-1.01	3.41	-0.64	3.39
0.7	-0.91	3.22	-0.97	3.44	-0.45	3.07
0.8	-1.02	3.26	-1.09	3.38	-0.53	2.91

In the Surveillance product, the numbers of samples are lower than the Doppler product because of the increased scan rate of the antenna and the lower pulse repetition frequency of the transmitter. Table 5 is an example of a typical Open RDA VCP Surveillance product with a one-degree beam width. Here we see that the post filter reflectivity bias is within the goal of 4 dB.

In table 6, the number of samples is reduced to 8 samples which would be representative of the typical half-degree beam width Super Resolution product. Here, we see that none of the post filter reflectivity biases are quantitatively usable.

Table 5, Surveillance–Reflectivity; NS=16, SNR=10dB

	CSR= 10 dB		CSR = 30 dB		CSR = 50 dB	
V/V_n	Pbias	SD[P]	Pbias	SD[P]	Pbias	SD[P]
0.0	-0.91	2.85	-1.13	3.29	0.60	3.14
0.1	-0.99	2.91	-1.06	3.36	-0.43	3.18
0.2	-0.88	2.82	-1.24	3.37	-0.43	3.21
0.3	-0.90	2.84	-1.01	3.11	-0.24	3.04
0.4	-0.95	2.71	-0.89	2.94	-0.16	3.05
0.5	-0.70	2.64	-0.8	2.78	-0.17	2.95
0.6	-0.65	2.51	-0.56	2.75	0.21	2.90
0.7	-0.46	2.46	-0.46	2.5	0.45	2.87
0.8	-0.41	2.42	-0.31	2.45	0.59	2.76

Table 6, Surveillance–Reflectivity; NS=8, SNR=10dB

	CSR= 10 dB		CSR = 30 dB		CSR = 50 dB	
V/V_n	Pbias	SD[P]	Pbias	SD[P]	Pbias	SD[P]
0.0	-0.45	4.60	15.28	4.51	35.30	4.33
0.1	-0.32	4.26	15.28	4.39	35.34	4.33
0.2	-0.39	4.24	15.27	4.50	35.29	4.46
0.3	-0.19	4.02	15.25	4.45	35.36	4.22
0.4	-0.11	3.88	15.37	4.39	35.28	4.30
0.5	-0.04	3.66	15.25	4.53	35.16	4.46
0.6	0.10	3.85	15.46	4.16	35.34	4.25
0.7	0.26	3.55	15.36	4.17	35.26	4.34
0.8	0.44	3.40	15.01	4.47	35.23	4.41

(b) Real Weather

Most of the benefits reported on the effects of Super Resolution focus on increased severe storm detection. One such severe storm was recorded by NSSL on the KOUN radar on May 8, 2003. This tornado swept through Oklahoma City and the surrounding metropolitan areas. The evaluation team acquired the NSSL level I data from this case for the phase II GMAP evaluation. The team reprocessed this data in the various Super Resolution formats on the Open RDA system. Figures 1 through 10 show the tornado to the northwest of the KOUN radar (axis are range bins and color scale is dBZ for reflectivity and ms^{-1} for velocity). The number of samples used to create the one-degree beam width was 54 and the number of samples for the half-degree beam width was 25. A full analysis of the data in the proposed Super Resolution formats that generated these images has not been completed at present.

Figure 1 is a depiction of the Open RDA reflectivity product with reflectivity generated from 1 km range bins and 1 degree in beam width. This figure has no filtering applied. As can be seen, the tornado vortex signature (TVS) indicating a tornado is obscured by the surrounding clutter. With the GMAP filter applied, the TVS becomes very apparent as shown in Figure 2.

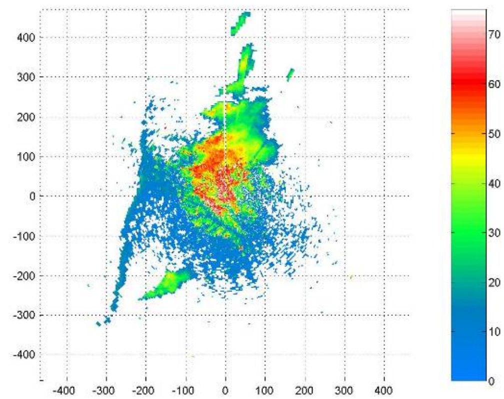

Figure 1, Unfiltered Reflectivity-ORDA

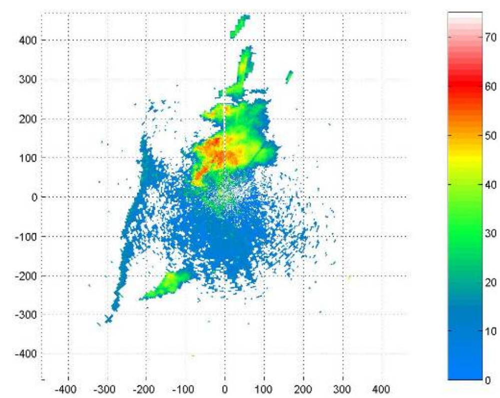

Figure 2, Filtered Reflectivity-ORDA

Figures 3 through 5 show the various Super Resolution reflectivity products. In Figure 3, the range resolution is increased to 250 meters. Then in Figure 4, the azimuth resolution is increased to half-degree while maintaining the one-degree beam width. Finally in Figure 5, the beam width is narrowed to half-degree. Normally, the RDA applies a threshold value to the product to clean up the noisy display. The evaluation team purposefully turned off threshold to better analyze the entire range of values.

The images in these figures are representative of a Doppler reflectivity product. Although these products are usually combined with the Surveillance product at the lower tilts to create a composite reflectivity product, it is very useful to evaluate the Doppler reflectivity separate from the Surveillance reflectivity to ensure NTR compliance.

As can be seen in the Super Resolution reflectivity products, low SNR areas are more noticeable. This is a by-product of 250 kilometer range resolution. The one-kilometer reflectivity product averaged four 250 kilometer range cells reduces this effect.

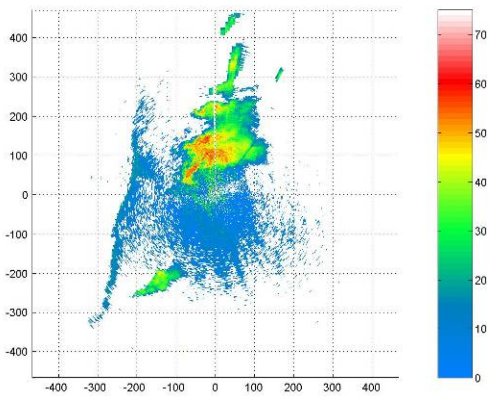

Figure 3, Filtered Reflectivity-Super Resolution 1

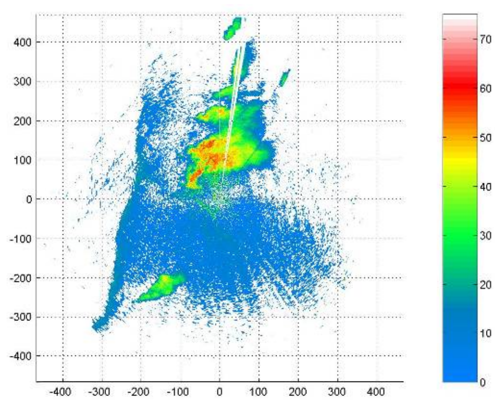

Figure 4, Filtered Reflectivity-Super Resolution 2

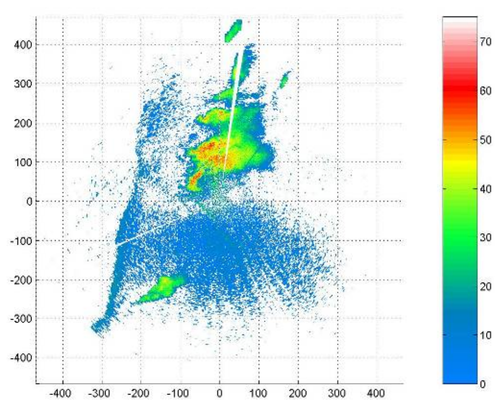

Figure 5, Filtered Reflectivity-Super Resolution 3

The velocity products associated with the reflectivity images above are shown in figures 6 through 9. Figures 6 and 7 show the velocities for the TVS using quarter kilometer range bins. These velocity products had a threshold of about 2.5 dB applied. In Figure 6, we see the TVS is completely obscured by the presence of clutter with no filtering applied.

In Figure 7, the GMAP filter clearly shows the presence of a large velocity gradient at the site of the tornado. There is no difference in the velocity products for the first Super Resolution enhancement from the Open RDA Doppler products since the velocity and spectrum width products are already displayed at a range resolution of 250 meters.

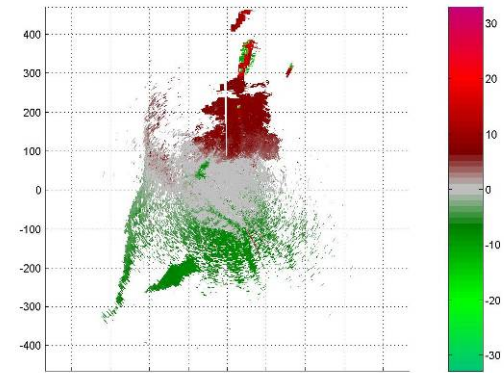

Figure 6, Unfiltered Velocity-ORDA

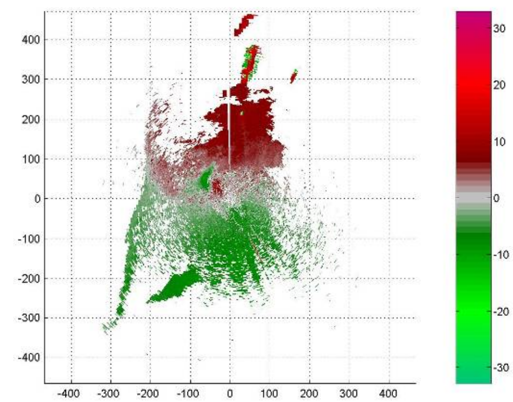

Figure 7, Filtered Velocity-ORDA

In Figure 8, the velocity product is displayed for an azimuth resolution that is increased to half-degree while maintaining the one-degree beam width. In Figure 9, the beam width is narrowed to half-degree. Note that there is no threshold applied to either velocity product in figures 8 or 9. Again this was done purposefully to analyze the full range of values in the velocity product.

SUMMARY

The team has not completely analyzed the results of the data thus far presented. Further investigation into the low velocity regions of the Super Resolution products is warranted. The simulations indicate that there may be problems in resolving low velocity meteorology in Super Resolution reflectivity products, but the real weather reflectivity products do not bear this out. If we look at the reflectivity fields for the Doppler products in Figure 5 and compare it to Figure 2, we do not see the large biases along the zero-mean velocity line that would be expected from the simulations.

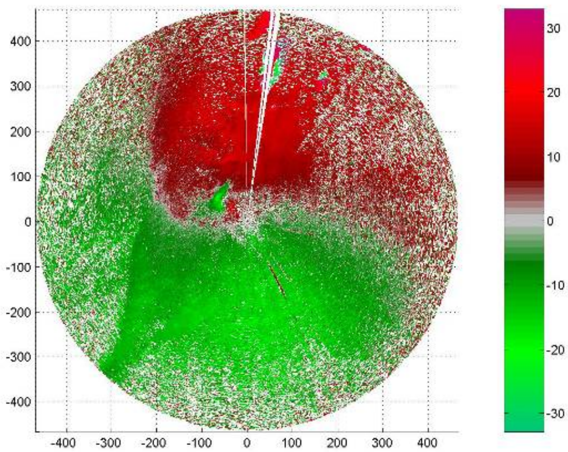

Figure 8, Filtered Velocity-Super Resolution 2

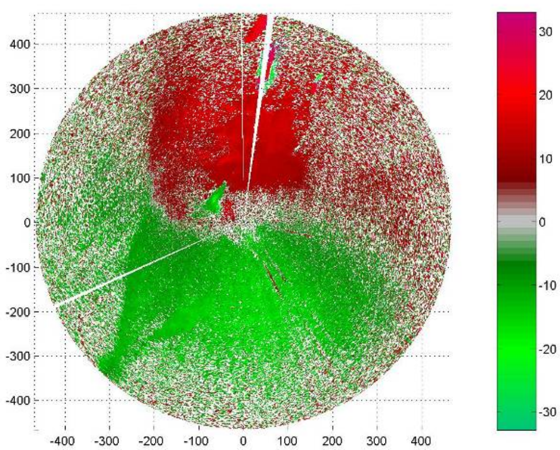

Figure 9, Filtered Velocity-Super Resolution 3

To completely assess Super Resolution performance and its ability to meet the NTR, the team will need to analyze more simulations and playback archived level I data from real weather. Currently progress is hindered because the evaluation team is using an older version of software (RVP8 version 8.04.3) than is used on the Open RDA system (RVP8 version 8.06.13). Version 8.06.13 uses a SIGMET utility called TS Archive to collect level I data; however, full playback with control of processing parameters is unavailable. Version 8.04.3 does not include all the latest processing capabilities such as batch mode and cannot play back TS Archive data. This version does allow full control of processing parameters upon playback. A temporary work around is to record using L1RP on RVP8 software version 8.06.13 and playback on RVP8 software version 8.04.3, but this does not allow play back of batch mode products. The ROC is working with SIGMET and developing tools that will provide the capability to playback TS Archive acquired data (Rhoton, 2005).

Another area that the evaluation team must consider is the compatibility of Super Resolution with other new science enhancements. One such enhancement is the R/V mitigation project that implements S/Z-2 phase coding (Saxion, 2005). The dilemma is that the S/Z-2 phase coding scheme needs 64 pulses to properly cohere each CPI; whereas Super Resolution may only have half that number of samples.

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