12B.8 HIGH-RESOLUTION WSR-88D BASE DATA ON THE KOUN RESEARCH RADAR

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1. INTRODUCTION

High-resolution WSR-88D base data has the potential of increasing the detection range of mesocyclone and tornado vortex signatures thus leading to increased warning times for severe thunderstorms and tornadoes. It has been shown through simulations that both types of signatures can be detected at ranges 50% greater than the current detectable ranges using 0.5° sampling rather than the standard 1° sampling (Wood et al. 2001; Brown et al. 2002). Increasing the reflectivity resolution from 1 km to 250 m improves the spatial resolution of the reflectivity field which enhances the visibility of mesocyclone and tornado vortex signatures. Both of these assertions were supported using time series data from the 3 May 1999 tornadic storms in Oklahoma (Wood et al. 2001; Brown et al. 2002). The improvements in detection and identification of signatures should lead to increased warning times and reductions in property damage, injuries, and loss of life.

High-resolution base data for the WSR-88D network is an important goal of the NEXRAD Product Improvement (NPI) program. It is one of the enhancements that is expected to quickly follow the deployment of the Open Systems Radar Data Acquisition (ORDA) portion of the WSR-88D system (Saffle et al. 2003). The National Severe Storms Laboratory (NSSL) received funding from the NPI program to examine the feasibility of high-resolution base data on the WSR-88D system. Modifications were made to both the Radar Data Acquisition (RDA) and Radar Product Generation (RPG) portions of the system as part of this study. The following sections describe the initial implementation decisions, the modifications that were made, and some of the consequences of those modifications. Preliminary results are shown for data collected using NSSL's KOUN research radar.

2. INITIAL IMPLEMENTATION DECISIONS

The current WSR-88D base data is collected at 1° intervals with 1 km resolution for reflectivity and 250 m resolution for Doppler velocity and spectrum width. High resolution base data is collected at 0.5° intervals with 250 m resolution for all of the spectral moments. If the same rotation rates are used, the high-resolution data will have larger errors since only half of the pulses are collected for each radial. The standard deviation of the measurements will increase by a factor of $\sqrt{2} \approx 1.4$ (sometimes less for reflectivity since it is measured on a logarithmic scale). The antenna rotation rates could be reduced by a factor of two to keep the same errors, but doubling the time to collect a Volume Coverage Pattern (VCP) is not practical. Our initial suggestion is to keep the current rotation rates and give users access to high-resolution base data for visual inspection. In the future, other enhancements will lead to high-resolution base data with lower errors which could completely replace its low-resolution counterpart.

The high-resolution base data was implemented as a new RPG product, but the ultimate goal is to use it to generate all of the RPG products. Most of the algorithms cannot ingest the high-resolution base data and will have to be modified in the future to use it when appropriate. Until all of the RPG algorithms are modified, low-resolution data still needs to be produced for the unmodified algorithms. Both low and high resolution data could be sent from the RDA or low-resolution data could be computed from high-resolution data at the RPG. Although the base data computed at the RDA will be more accurate than that produced at the RPG because of quantization errors, it was decided that the decrease in accuracy was an acceptable tradeoff. The dual-stream approach of sending both types of data from the RDA would have significantly increased the needed bandwidth which seemed unwise in light of other future enhancements that will also necessitate increased bandwidth (e.g. dual polarization).

Our initial decisions resulted in a single high-resolution data stream being computed at the RDA. This data is then displayed at full resolution using the high-resolution product and recombined to form low-resolution data for the other RPG products. This approach will provide the most benefits at this stage without requiring significant changes to the WSR-88D system.

3. RDA MODIFICATIONS

The modifications to the RDA fell into two major areas: modifications for 0.5° azimuth sampling and modifications for 250 m reflectivity. The modifications for 0.5° azimuth sampling were straightforward. The VCP definitions were modified so that each radial contained half the number of pulses compared to a 1° radial. The signal processing and base data stayed the same, but twice as many radials were sent to the RPG. Some minor changes were made in the descriptions of the VCP and of the base data so that the two types could be told apart, but no major changes were necessary.

The modifications for producing 250 m reflectivity were more significant since the signal processing had to be expanded and the format of the base data had to be altered. The signal processing algorithms in the KOUN research radar are coded in the C language using a

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PowerPC-based multiprocessor subsystem (Zahrai et al. 2002). These algorithms were migrated from the original WSR-88D to a SHARC-based system and finally to the current PowerPC-based one (Torres and Zahrai 2002). The signal processing tasks are divided among modular functions which allowed us to reuse existing software with some minor modifications. This greatly simplified the task of adding 250 m reflectivity without affecting the rest of the code. The decision was made to add processing for the 250 m reflectivity without making any major changes to the existing processing stream. For example, the Doppler scan from a split surveillance/Doppler cut continues to use the 1 km stored reflectivity in order to unfold velocity and spectrum width in range even though the 250 m reflectivity data is computed and sent for the high-resolution base data. This decision minimized the impact of our changes on the rest of the system and simplified testing.

The computation of 250 m reflectivity data was added to all of the current processing modes that produce reflectivity data. The most substantial change to the signal processing functions was the modification of the functions that compute the echo power and the reflectivity. Both of these functions were modified to produce 250 m data in addition to 1 km data. The raw power that is used to compute both 1 km and 250 m reflectivity data already has a resolution of 250 m so these updates did not necessitate any changes to the hardware.

The most tedious part of the high-resolution updates was altering the format of the base data. Although the base data message in the current WSR-88D allows for variable-sized base data, a fixed size had always been used. We decided to use the variable-sized capabilities of the message rather than change to a larger fixed-size message. This keeps the base data that is sent as small as possible and also simplifies any future changes to the base data. It does require some minor changes in the RPG to match the format needed by the algorithms.

The final result of the RDA changes was a high-resolution data stream being sent to the RPG using a variable-sized base data message. The amount of data being sent is increased by a factor of about 1.6 for batch mode and raw Doppler mode but is actually decreased by a factor of about 2 for the split cuts because the variable-sized message is more efficient when all of the spectral moments are not sent.

4. RPG MODIFICATIONS

The modifications to the RPG also fell into two major areas: adding the new high-resolution base data product and recombining the high-resolution data into low-resolution data for the other algorithms. To add the new product, high-resolution versions of the base data processing, velocity dealiasing, and digital base data product generation algorithms were created from existing low-resolution algorithms. To minimize code duplication, the high-resolution algorithms share the same source code with their low-resolution counterparts. Since the existing RPG internal base data format is of fixed length, a new variable-length base data format was defined to allow high-resolution data to be passed to the new algorithms. The Level III base products produced by the algorithms can be displayed by the user to reap the benefits of high-resolution base data.

The recombination algorithm was a more significant modification. Each low-resolution reflectivity value is made up of eight high-resolution values. The high-resolution values are converted to estimated signal powers in the linear domain, averaged, and then converted back to reflectivity to form a low-resolution value. The computations for velocity and spectrum width are slightly more complex. Since the lag-one autocorrelation is used to compute the velocity and spectrum width, the autocorrelation for both of the high-resolution values can be recovered and averaged to produce accurate low-resolution values. The argument of the autocorrelation can be directly recovered from the velocity, and the magnitude of the autocorrelation can be recovered by solving the equation used to compute the spectrum width

$$w = \frac{\lambda}{2\pi T_S\sqrt{2}}\left[\ln\left(\frac{S}{|R_1|}\right)\right]^{\frac{1}{2}},\quad |R_1| = \frac{S}{\exp\left(\frac{2\pi w T_S\sqrt{2}}{\lambda}\right)^2}, \qquad (1)$$

where w is the computed spectrum width, λ is the wavelength, T_S is the pulse repetition time (PRT), S is the high-resolution signal power estimate (recovered from the high-resolution reflectivity), and R_1 is the estimated lag-one autocorrelation. The result of the recombination is low-resolution data (1 km reflectivity and 250 m velocity and spectrum width) sampled every 1° which can be input into the RPG algorithms.

The recombined low-resolution base data computed at the RPG is not identical to the low-resolution base data that would be computed at the RDA. There are five sources of error that have been examined: (1) quantization of the high-resolution base data, (2) strong-point clutter removal, (3) ground-clutter filtering, (4) spectrum width bias, and (5) thresholded high-resolution data. The quantization of the high-resolution data is the result of base data formatting that is done in the RDA. Reflectivity is quantized to 0.5 dB, and velocity and spectrum width are quantized to 0.5 m s^{-1} (or less frequently 1 m s^{-1}). These quantization errors average out most of the time but can result in errors on the order of one quantum in certain cases. Unlike the other sources of errors, quantization errors can affect any portion of the base data.

The strong-point clutter removal and ground-clutter filtering errors are more localized. The differences from strong-point clutter removal occur when strong-point clutter appears in one of the 0.5° radials used for the recombine and not the other. Data is interpolated from adjacent range bins along the radial to replace the contaminated bin. This bin is then averaged with a bin that does not have strong-point clutter. The final value computed by the recombination algorithm should be closer to the true value without point clutter since a value from the uncontaminated radial is used in the computation. Conversely, in the 1° case only interpolated values would be used. The ground-clutter filtering case is similar to the strong-point clutter case because a difference occurs when one of the bins from a 0.5° radial is filtered and the corresponding bin from the other radial is not. Since the decision to filter depends on how close the radial is to the corresponding radial from the clutter map, the higher resolution of the 0.5° radials should result in closer matches to the clutter map and better results overall.

A spectrum width bias error occurs when a high-resolution spectrum width value is negative and set by the RDA to zero. This negative value would be added to other values before being thresholded if the RDA were to compute the low-resolution data. Since the RPG recombine algorithm uses a zero rather than the negative value, the result is a larger spectrum width value. The current assumption is that these errors will not be very prevalent and should only occur in areas where the spectrum width estimates are relatively noisy.

The last source of errors is similar to the spectrum width bias. The high-resolution reflectivity values that are below the reflectivity threshold are not marked as significant, and the values are set to zeros. If, for example, a low-resolution reflectivity bin consists of five significant return bins and three insignificant return bins, deciding whether the low-resolution bin is significant or not is difficult. The final result may depend on information that is no longer present in the high-resolution bins. If a representative value is used for the bins that have no information and the data is re-thresholded, the results should be reasonable overall. In any case, this only occurs in areas that are close to the threshold, normally low reflectivity areas. The difference between a very small significant return and no significant return should not affect the RPG algorithms in a significant way.

5. RESULTS AND CONCLUSIONS

The feasibility of high-resolution base data was shown through a relatively straightforward set of modifications to the RDA and RPG. Even though the full benefits of high-resolution data may not be seen until some of the RPG algorithms are modified, the approach that we suggest achieves most of the advantages of high-resolution data for the user without making major changes to the system. This should ensure early implementation on the ORDA after it is deployed.

An example of high-resolution reflectivity data from the KOUN research radar in Norman, Oklahoma is shown in Figure 1. The small-scale features are much clearer in the high-resolution image, and the occurrence of stronger signatures compared to the low-resolution image show how the finer resolution can enhance the detectability of phenomena of interest. This combination of better detectability and feature enhancement on the WSR-88D is the foundation for future increases in tornado warning times.

6. REFERENCES

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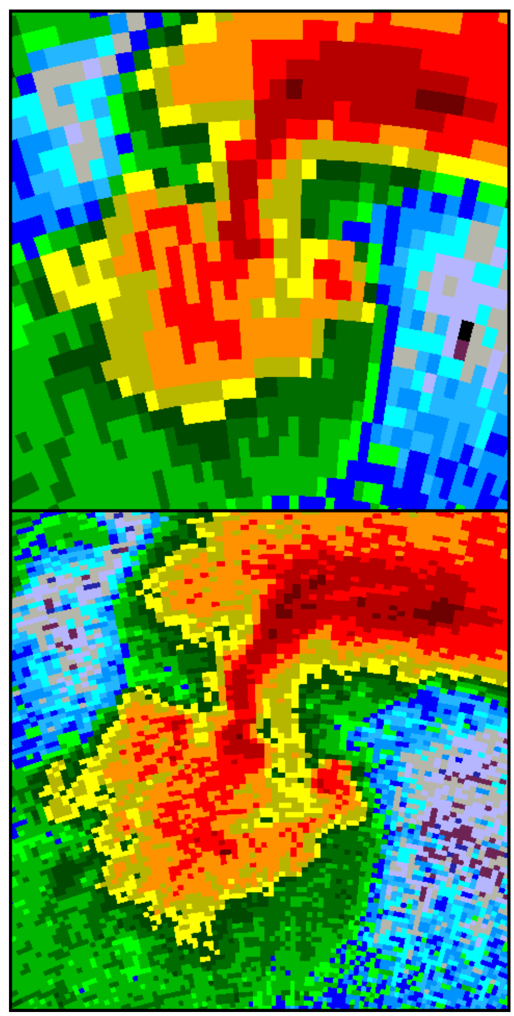

Figure 1. Low-resolution and high-resolution reflectivity from a tornado outbreak in Oklahoma City, 9 May 2003.