365 NEW SCIENCE FOR THE WSR-88D: VALIDATING THE DUAL POLARIZATION UPGRADE

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1. BACKGROUND

From September 2009 through May 2010, the Radar Operations Center (ROC) Engineering team supported the Data Quality Dual Polarization Subcommittee (DQDP) by quantitatively validating the L-3 Stratis and Baron Services (L-3/Baron) upgrade of the WSR-88D from a single polarization signal to a dual polarization signal (referred to as 'dual pol'). The DQDP Subcommittee is a multi-disciplinary, multi-organizational group of meteorologists, engineers, scientists, testers, and technicians from ROC Engineering Branch, ROC Applications Branch, ROC Operations Branch, National Severe Storms Lab, Office of Science and Technology, Office of Hydrology, and Warning Decisions Training Branch who monitor the data quality of the dual pol upgrade. This paper summarizes the results of the analyses performed by ROC Engineering which focused on maintaining the base moment data quality. The goal was to ensure that the dual polarization system was functioning properly and to help determine readiness for transitioning to System Test, 25 May 2010. Because most of these tests were developed in response to active issues that evolved with time, this paper takes a chronological approach when discussing tests and their results.

In a parallel effort during this time, the DQDP subcommittee subjectively analyzed the quality of both base moments and dual pol variables and were fortunate to have a variety of significant weather events including winter weather, flash flooding, tornado outbreaks, and damaging hail storms [Schlatter, 2011].

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2. COVERAGE COMPARISON

On 21 September 2009, data began flowing from the radar with the dual polarization upgrade, KOUN. The DQDP subcommittee began subjectively evaluating the data. The area of data coverage from KOUN appeared to be much less than expected when comparing to the co-located ROC test bed WSR-88D, KCRI. Because the total power is split between horizontal and vertical channels in the dual polarization system, the DQDP subcommittee expected to see a 3 dB loss in sensitivity, which is directly proportional to coverage when noise is measured accurately. The DQDP subcommittee needed a way to quantify the observed coverage loss.

In October 2009, the ROC created a sensitivity test that utilized Engineering's existing playback system and ROC Applications Branch's coverage comparisons. Radar theory shows that coverage differences are directly proportional to the sensitivity differences between two radars, assuming that the noise measurements are correct. In a first attempt to quantify the sensitivity difference, the ROC Engineering played back KCRI Level I data with increasing SNR thresholds saving the Level II data. ROC Applications Branch performed bin count and areal ratio comparisons that Level II data. The sensitivity difference was determined to be the amount added to the SNR threshold to yield the same coverage as original KOUN data. The results were good enough for a general conclusion, but had too much variance from case to case to determine an absolute number for the sensitivity difference. Through this method, the ROC determined that the dual polarization upgrade was exhibiting a 6 – 8 dB loss in sensitivity (i.e., KOUN was 6 - 8 dB less sensitive than KCRI).

In December of 2009, L-3/Baron redesigned the receiver portion of the dual polarization hardware to correct a dynamic range issue. With this redesign, the sensitivity of the receiver was also improved. In February 2010, the ROC performed sensitivity tests again finding that KOUN was 5 - 6 dB less sensitive than KCRI. While an improvement, it was not close to the originally expected 3 dB difference.

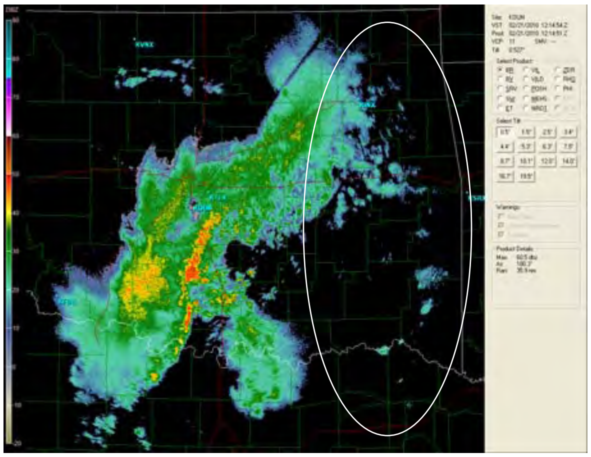

Figure 1. KOUN Reflectivity from 21 February 2010 at 1215 UTC.

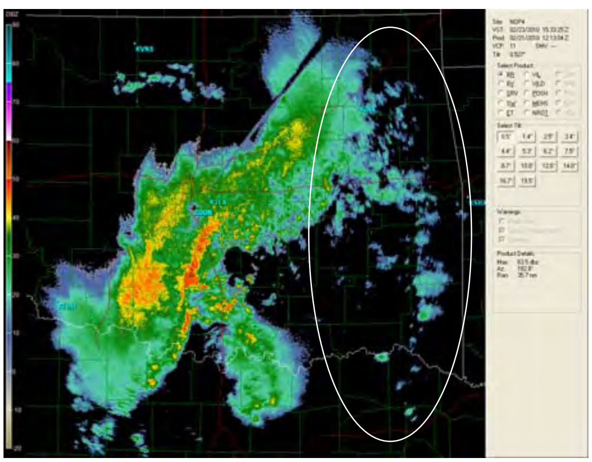

Figure 2. KCRI Reflectivity from 21 February 2010 at 1213 UTC. Note the larger areas of coverage when compared to Figure 1 to the east and southwest.

On 21 February 2010, a line of thunderstorms moved across Oklahoma. The data case analyzed was reflectivity from 0.5º elevation Surveillance scan of a line of thunderstorms from the southwest to the northeast with a heavy rain and a low melting layer of 4000-5000 ft. The beginning time of the Volume Coverage Pattern (VCP) from KOUN was 1215 UTC and the beginning time of the VCP from KCRI was 1213 UTC. Both radars were operating with VCP 11. Figure 1 shows a Plan Position Indicator (PPI) of reflectivity image for the event. A strong convective weather case is not ideal when looking for sensitivity differences because there are few areas with weak weather returns. However, sensitivity differences can be seen in the areas marked by the white oval in regions at the farthest ranges to the east and southeast.

Figure 1 shows reflectivity from the dual pol radar, KOUN. Figure 2 shows reflectivity from the co-located legacy radar, KCRI. Note the increased coverage in this image. Figure 3 shows a reflectivity PPI generated from playing back Level I data from KCRI with an SNR threshold increased by 5 dB. Note that the coverage of Figure 3 now closely resembles the coverage in Figure 1. KCRI Level I data was recorded and used as input for subsequent playback iterations. Each iteration increased the SNR threshold: specifically, SNR+3.0 dB, +4.0 dB, +5.0 dB, +5.5 dB +6.0 dB, +6.5 dB, and +7.0 dB. Figure 4 shows a bar chart comparing the ratio of

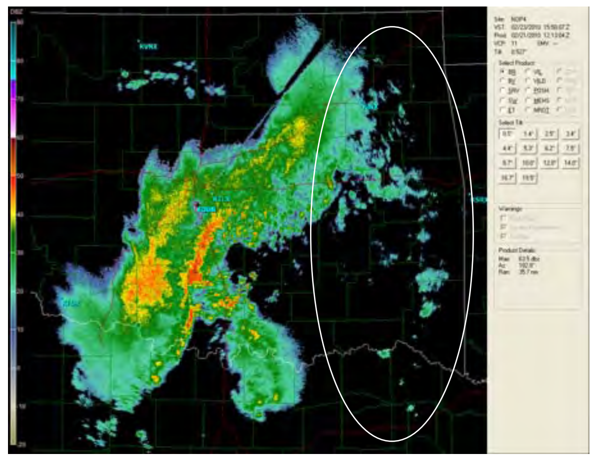

Figure 3. KCRI Reflectivity from playing back Level I data with increasing the SNR threshold by 5.0 dB. Note the weaker regions to the east compare well with Figure 1.

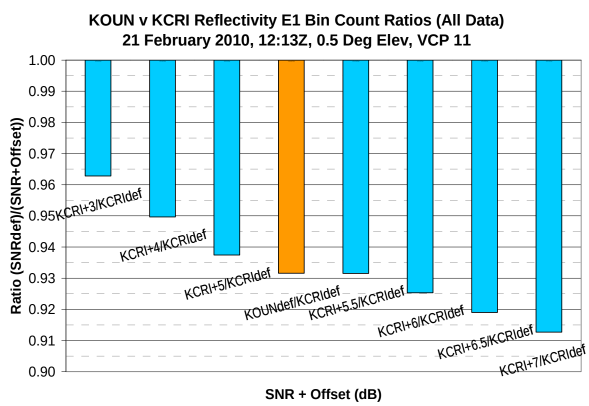

Figure 4. A bar chart comparing the ratio the bin count of reflectivity values from playback data with increasing SNR threshold and the bin count of reflectivity values of the originally recorded KCRI reflectivity (KCRI def). The orange bar is the bin count ration of the originally recorded reflectivity from KOUN and the originally recorded KCRI. The bin count comparisons show that KOUN is nearly 5.5 dB less sensitive than KCRI.

the bin count of reflectivity values from playback data with increasing SNR threshold and the bin count of reflectivity values of the originally recorded KCRI reflectivity (KCRI def). The orange bar is the bin count ratio of the originally recorded reflectivity from KOUN and the originally recorded KCRI. The bin count comparisons show that KOUN is nearly 5.5 dB less sensitive than KCRI. Not only do sensitivity differences between the two radars affect these comparisons, but so do time differences between KOUN and KCRI data (in this example, almost 2 minutes) and transmitting frequency differences between the two radars. While this method provides a general comparison, a more refined analysis was needed.

3. SENSITIVITY AND CALIBRATION

To gain deeper insight into comparisons of the sensitivity of KCRI and KOUN, ROC Engineering plotted SNR as a function of range for both radars on the same graph, deriving SNR from reflectivity and noise data provided within Level II data. With this graph, KOUN performance could be visually compared to KCRI performance with respect to the known varying weather conditions down a single radial. The same data case as that used in the coverage comparison was used for further analysis here. Figure 5 shows a PPI of reflectivity image for that event. The two radials analyzed are highlighted by the white lines.

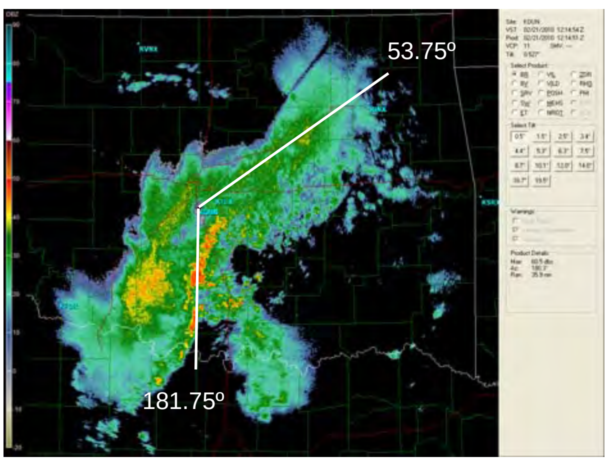

Figure 5. Reflectivity from the 21 February 2010 thunderstorm event from earlier examples with analyzed radials marked with white lines.

Figure 6 shows the graphs associated the radial at 181.75º azimuth which contains very strong reflectivity values indicating a mix of big drops and hail. The two lower graphs will be discussed later. The upper left image is SNR vs. range with KCRI plotted in blue and KOUN plotted in green. The upper right image is the difference of KCRI SNR minus KOUN SNR for each bin down the radial. A red line beginning at 45 km is the region where the mean SNR difference was calculated. Clutter filtering was applied to all bins within 45 km; therefore that region was excluded from the mean calculation. The mean SNR difference for this radial is

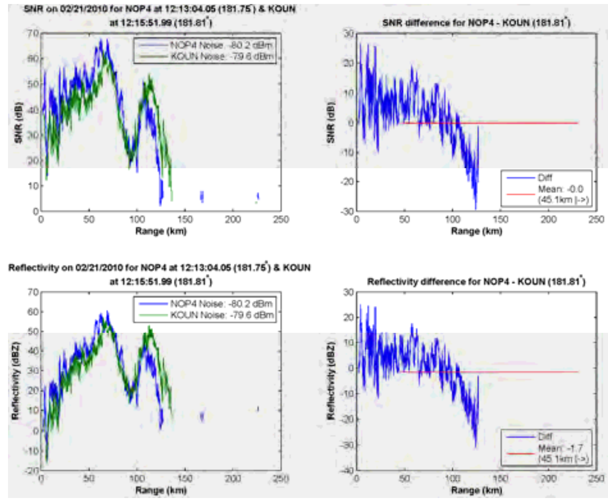

Figure 6. Radial analysis of 181.75º azimuth from the 21 February 2010 storm. The graphs are as follows: upper left: SNR vs. range of both KOUN (green) and KCRI (blue), upper right: KCRI-KOUN SNR, lower left: reflectivity values vs. range of both KOUN (green) and KCRI (blue), lower right: KCRI-KOUN reflectivity. Note KCRI has greater values in lower regions of reflectivity while KOUN has greater values in regions of higher reflectivity (greater than 50 dBZ).

an unexpected 0 dB. However, examining difference plot in the upper left quadrant shows that in regions of moderate reflectivity, indicating drops in Rayleigh scattering, KCRI has higher sensitivity than KOUN. Farther down the radial in the regions of rain/hail mix, KCRI shows less sensitivity than KOUN. This is due to the different operational frequencies of KOUN and KCRI where it has been shown that different frequencies interact with non-Rayleigh scatterers differently. [Melnikov et al., 2010].

Figure 7 shows a comparison plot of the radial at 53.75º azimuth where reflectivity values were below 40 dBZ. Notice how consistently KCRI has higher SNR values than KOUN. The top right graph shows that KOUN is approximately 4.8 dB less sensitive than KCRI for all range bins. For this radial, the mean difference was closer to what was expected.

Taking the next logical step, ROC Engineering developed plots showing average difference for all radials, referred to an the 360º SNR/dBZ Mean Difference plot, with the mean SNR difference between KCRI and KOUN plotted in green (the mean dBZ difference is plotted in blue and will be discussed later). Using information gleaned from the 360º SNR Mean Difference plot and information shared by L-3/Baron, ROC systems engineers performed an in-depth analysis of the sensitivity of the WSR-88D and the dual polarization upgrade. The sensitivity analysis included an investigation of the impacts that operational frequency differences between KOUN and KCRI had on sensitivity. From the beginning of the project, it was assumed that the frequency differences would be minimal. However, the sensitivity analysis revealed that KOUN was 1.5 dB less sensitive than KCRI due to

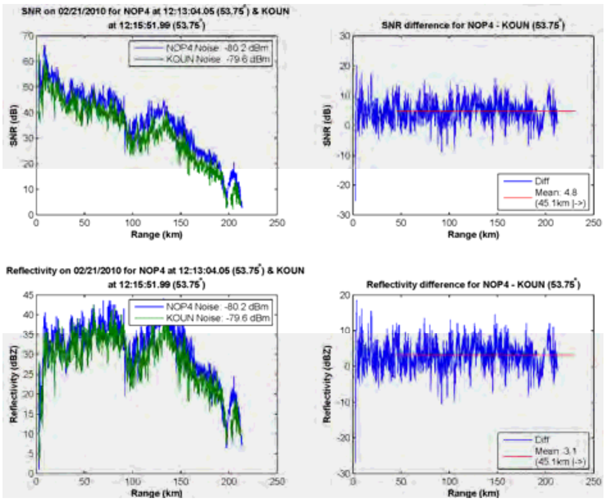

Figure 7. Radial analysis of 53.75º azimuth from the 21 February 2010 storm. The graphs are as follows: upper left: SNR vs. range of both KOUN (green) and KCRI (blue), upper right: KCRI-KOUN SNR, lower left: reflectivity values vs. range of both KOUN (green) and KCRI (blue), lower right: KCRI-KOUN reflectivity. Note how this radial of reflectivity values less than 50 dBz had consistent differences between the two radars.

frequency differences alone. ROC systems engineers analyzed the L-3/Baron hardware design and found that the calculated loss due to installing the dual polarization modifications, including the 3 dB loss from splitting the power, was 3.5 dB. When combining the losses due to frequency and the losses due to the dual polarization upgrade, ROC Engineering concluded that KOUN is

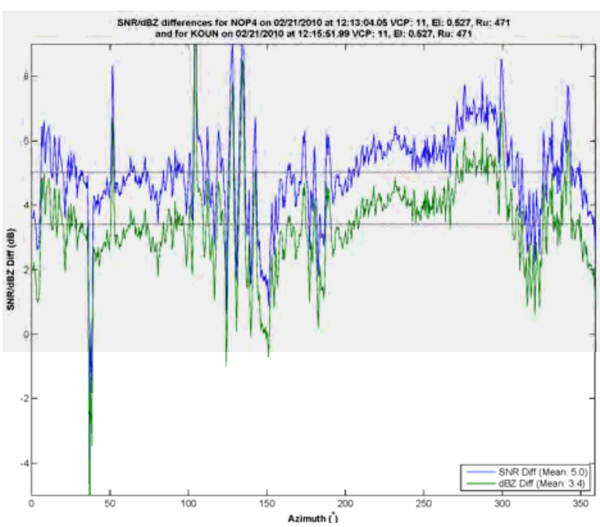

Figure 8. 360º Mean Difference SNR/dBZ for the 21 February 2010 weather event. Note how the variations in the mean differences are less in regions where a radial has a significant number of bins with reflectivity values > 10 dBZ and < 40 dBZ.

5 dB less sensitive than KCRI (1.5 dB + 3.5 dB) [Ice, et al., 2011]. The dual polarization upgrade alone was determined to have less sensitivity loss than the maximum acceptable loss of 4 dB defined by the Subject Matter Expert Panel convened in December 2009.

After completing the analysis of the sensitivity differences between KOUN and KCRI, ROC Engineering began to investigate why KOUN reflectivity values were, on average, 4 dB less than reflectivity values from KCRI. The bottom left graph in Figures 6 and 7 shows reflectivity (Z) vs. range for both KOUN (green) and KCRI (blue). The bottom right plot shows the difference between KCRI and KOUN with the average for the radial beyond 45 km printed in the corner. ROC Engineering created the 360º Z Mean Difference plot to quantize reflectivity calibration differences. Reflectivity calibration determines dBZ_0, a calibration value that adjusts for radar hardware thus ensuring that reflectivity values are accurate with respect to the Weather Radar equation. ROC Engineering worked with L-3/Baron to understand and correct all of the differences in dBZ_0, which wasn't one big fix, but many small changes to both KOUN and KCRI. Some of the small changes include L-3/Baron correcting their reflectivity calibration procedures and ROC Engineering tuning the antenna gain value and correcting a long-standing transmit path loss on KCRI. ROC Engineers and L-3/Baron were able to reduce the calibration differences to about 1 dB which is within acceptable limits.

4. VALIDATING BASE MOMENTS

In a parallel effort to the analysis of the sensitivity and reflectivity calibration issues, ROC Engineering performed a signal processing validation. The goal of the validation was to show that the dual polarization system did not change how the Base Moments (reflectivity, velocity, and spectrum width) were calculated. For each signal processing mode with clutter filtering disabled, ROC Engineers played the same Level I data through the baseline version of software and through a dual polarization version of software and compared the results. For FFT, which is used in Split-Cut processing and Contiguous Doppler processing, there were some differences that resulted from an Vaisala software update for the RVP8 in the Dual Pol baseline. For Batch Cut processing there were explained differences. L-3/Baron dropped 1-2 high PRF pulses in order to achieve reasonable correlation coefficient values. When this was adjusted for in the baseline processing, the base moments from Batch Cut processing exactly matched. SZ-2 data processing showed no differences between baseline and dual-polarization processing. ROC Engineering completed the signal processing validation of the base moments after entrance into System Test by testing all major modes with clutter filtering enabled for all bins. Resulting differences between baseline and dual polarization processing had the same root causes as unfiltered processing. Completing this effort ensured that the dual pol base moments met the same requirements as the legacy WSR-88D for both non-clutter filtered and clutter filtered processing.

5. MONITORING SYSTEM STABILITY

ROC Engineering developed tools to extract and plot calibration information stored in status products from the Radar Product Generator (RPG). Calibration parameters, including noise, noise temperature, I_o, dBZ_0, and transmit power, for both short and long pulse, were collected from KOUN and KCRI. For each H channel calibration parameter, time series, and histogram graphs were created with data from both radars on the same plot. Having data from both radars on the same graph provided a means for showing how the two systems were performing relative to each other. Figure 9 shows an example of Noise vs. time for KOUN, KCRI, and KTLX. Missing sections of data from KOUN were due to a communications problem. From these graphs, ROC Engineering concluded that the new dual polarization NEXRAD design achieved greater calibration stability than the ROC KCRI test bed and the nearby KTLX radar. This indicates no issues with calibration stability are expected with the fielding of the new system.

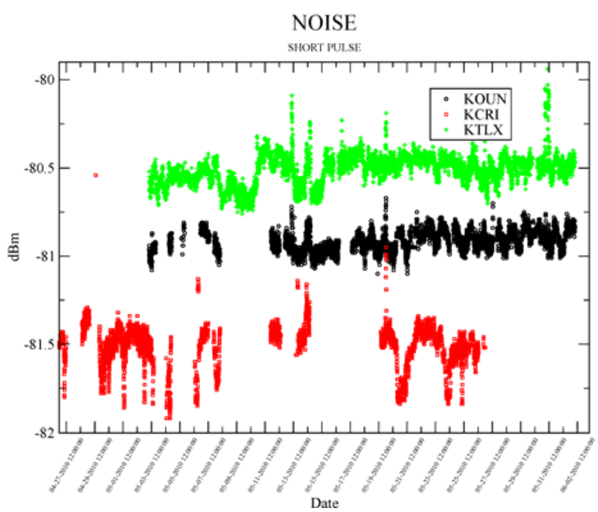

Figure 9. Noise vs. time for KCRI (red), KOUN (black) and KTLX (green).

6. CONCLUSIONS

The first goal of ROC Engineering when proving the dual pol upgrade was to verify that the WSR-88D base moments data quality was not degraded. Having a dual pol and a legacy radar co-located greatly facilitated the verification. ROC engineering has verified that the base moments from the dual pol upgrade have the same data quality as the existing WSR-88D, except for the expected 3.5 dB loss in sensitivity due to splitting the power and insertion losses of the new hardware.

7. ACKNOWLEDGEMENTS

The ROC Engineers would like to recognize L-3 Stratis and Baron Services for all their hard work and willingness to collaborate. Proving the dual pol upgrade was only possible through the combined efforts of all the branches of the ROC (especially Applications Branch), Warning Decision Training Branch, and the National Severe Storms Laboratory. Thank you all for sharing your knowledge, skills, and expertise so generously.

8. REFERENCES

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