J1.5 **VALIDATION OF RANGE CORRECTION ALGORITHM USING REAL-TIME RADAR DATA FROM STERLING, VA**

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1. INTRODUCTION

The Range Correction Algorithm (RCA) is a procedure developed by NOAA's National Weather Service (NWS) Office of Hydrologic Development (OHD) Hydrology Laboratory (HL) for real-time adjustment of range-dependent reflectivity biases in the Weather Surveillance Radar-1998 Doppler version (WSR-88D). The RCA corrects biases that are due to a nonuniform vertical profile of reflectivity (VPR) (Seo et al. 2000), one of the most important sources of error in WSR-88D rainfall estimates (Fulton et al. 1998). The RCA is currently being developed and under implementation in the Open Radar Product Generation (ORPG) system in OHD. The prototype RCA has been running since early 2003 for validation using real-time radar data from Sterling, VA (KLWX).

In this work, we have compared the original and range-corrected radar rainfall estimates to rain gauge values to verify the performance of the RCA in real-time operations, and to develop guidance for the usage of the RCA. This long-duration and extensive validation is a necessary supplement to the individual case studies performed in Seo et al. (2000).

2. DATA SET

The main product of the prototype RCA is the Adjustment Factor Array (AFA). It specifies the multiplicative adjustment factors to the radar rainfall within the 131 × 131 subsection of the Hydrologic Rainfall Analysis Project (HRAP) grid surrounding the radar site. These factors are used to adjust the radar rainfall estimates in the hourly Digital Precipitation Array (DPA) product. Here, we compare the original DPA, the DPA with RCA adjustment, and the rain gauge data to evaluate the RCA performance.

The prototype RCA has been running in HL since early 2003, and DPA, AFA, and other RCA products have been being archived. The archival period covers most of February, March, April, and May of 2003, though data gaps exist due to radar and local workstation outages. DPA at the top of hour and the corresponding AFA are used to generate hourly radar rainfall estimates with RCA adjustment. Table 1 lists the number of DPAs at the top of hour with precipitation (rain or snow) for this study period. It also lists the number of days for which the DPAs are available. Over the four-month period, there were 1,358 hours of DPA with precipitation (rain or snow), of which 217 hours are from February, 282 hours from March, 350 hours from April (Data on April 29 and 30 have serious Anomalous Propagation (AP) contamination and are excluded), and 509 hours from May.

For the comparison with rain gauge observations, we used 24-h precipitation observations ending at 1200 UTC collected by the National Centers for Environmental Prediction (NCEP). Those rain gauges identified as "suspect," based on automated consistency checks, were excluded from this analysis. The 24-h precipitation estimates from the radar are simply the summation of hourly DPAs from 1300 UTC to the following 1200 UTC. Both the original and RCA-adjusted 24-h radar

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precipitation estimates were compared with the gauge data. From the location of the gauge, the position of the matching HRAP grid can be obtained. A gauge-radar data pair is then defined as the 24-h precipitation amounts from the gauge and radar at the matching HRAP grid. Table 2 lists the number of gauge-radar pairs and the number of 24-h accumulations of these gauge-radar pairs available for each month. Note that, in each month, there are more than one thousand gauge-radar pairs.

Table 1. The number of DPAs with precipitation (rain or snow) and the number of days for which DPAs are available in each month of the analysis period.

Month	Feb.	Mar.	Apr.*	May
Hours of DPA	217	282	350	509
Days	17	24	26	31

*For two days in April, radar data have serious AP contamination. The numbers shown do not include these two days.

Table 2. The number of gauge-radar pairs and the number of 24-h periods for which the pairs are available in each month of the analysis period.

Month	Feb.	Mar.	Apr.*	May
Number of pairs	1,206	2,030	1,556	3,483
24-h periods	12	20	14	22

*See Table 1 note

3. EVALUATION RESULTS

3.1 *Radar-Only Evaluation*

Figures 1(a) and 1(b) show the radar precipitation accumulations from all 282 hours' worth of original and RCA-adjusted DPAs in March, respectively. The range circle in the figures indicates a radius of 230 km from the radar site. Without RCA adjustment, the bright band effect is readily visible between 70 and 150 km, particularly in the southeast and northwest part of the radar umbrella. After RCA adjustment, the bright band effects are significantly reduced, except in some areas adjacent to the terrain blockage in the southwest part of radar umbrella. Accounting for the effect of terrain blockage is not within the scope of this study and is not discussed further. It may also be seen that, with RCA adjustment, precipitation estimates near the edge of the radar umbrella are increased.

The effects of RCA adjustment are more evident in Fig. 1(c), which shows the difference in precipitation accumulation between the RCA-adjusted and unadjusted estimates. Nonzero differences appear in three concentric bands. Near the radar site is a white circular area with radius of about 40 km. In this area, little or no adjustment was made by RCA. Beyond the white circular area is a concentric band between ranges of about 40 km and 150 km. In this zone, the mix of green, blue, and black colors indicate significant reduction in precipitation estimates brought by RCA adjustment. The maximum amount of reduction is about 40 mm over the month. The exception is the small red area in the southwestern part where the second elevation angle is used for precipitation estimation due to beam blockage. In the far-range area is another concentric band with a mix of white, yellow and red colors. In this area, RCA adjustment increases precipitation estimates. The maximum increase is about 35 mm over the entire month.

As noted in the introduction, the main purpose of RCA is to reduce the range-dependent bias. To view this effect, the azimuthal averages of precipitation accumulation of the original (red dashed line) and the RCA-adjusted (blue solid line) are shown in Fig. 1(d). Note in Fig. 1(d) that the three ranges of no, negative, and positive adjustment correspond to the three annuli in the Fig. 1(c). The first is the close range with slant ranges less than 40 km. Over this range, RCA brings almost no adjustment. The second is the mid-range with slant ranges from about 40 km to 150 km. In this range, the azimuthal-mean precipitation with RCA adjustment is consistently smaller than that without adjustment, the result of RCA adjustment of the bright-band effect. The third is the far-range with slant ranges greater than 150 km. Over this range, the azimuthal-mean precipitation with RCA adjustment is consistently greater than that without adjustment, the result of RCA adjustment of radar sampling of frozen hydrometeors above the melting layer.

While the RCA adjustment in the far-range is not as pronounced as that in the mid-range, it is apparent that the range effects are indeed mitigated at all ranges.

Figures for other months (not shown) indicate similar results but the magnitude of adjustment to precipitation amounts brought by RCA are different due to different precipitation types. It is worth noting that the reflectivity fields on April 29 and 30 had very serious AP contamination. After the radar data in these two days are excluded, the results are similar to those from other months.

3.2 *Gauge-Radar Evaluation*

Figure 2 shows the gauge vs. radar scatter-plots of 24-h precipitation for March. The figure has four panels showing the original (top-left), with mean-field bias adjustment (top-right), with RCA adjustment (bottom-left), and with both mean-field bias and RCA adjustment (bottom-right). The reason for the mean-field bias adjustment is that radar rainfall estimates are subject to errors other than VPR effects, which, if unaccounted for in some way, may mask the effects of RCA and hence defeat the purpose of gauge-radar evaluation. Another reason for the mean-field bias adjustment is that the Precipitation Pre-processing System (PPS) in the current ORPG system has the mean-field bias adjustment functionality. Here, mean-field bias is defined as the average of the ratios of gauge-to-radar rainfall of all gauge-radar pairs in each 24-h period (note that this is different from the definition of the operationally produced estimates of mean-field bias). The RCA adjustment is applied before mean-field bias adjustment. In each figure, different symbols are used to represent gauge-radar pairs from different slant ranges. “Red stars” are from the near-range (less than 70km), “blue crosses” from the mid-range (70 km to 140 km), and “green circles” from the far-range (greater than 140 km). Figures for other months are not shown.

It was found that results for February and March were quite similar. In these two months, even though the winter Z-R parameters (130, 2.0) were used, radar significantly underestimated precipitation (see the left panels). Note that, even though the mean-field bias adjustment corrected the overall underestimation, RCA-unadjusted estimates had a very large scatter (see the top-right panel). RCA-adjusted estimates, on the other hand, had a significantly reduced scatter (see the bottom-right panel).

The situation in April (not shown) was somewhat different from February and March. Radar still underestimated precipitation but not as severely as in February and March. However, the radar rainfall estimates had a larger scatter when compared to those in February and March. It was suspected that AP contamination might have been a contributing factor. Even though the two days with serious AP contamination were excluded, there might have been other days with less severe, but still significant, AP contamination. Nevertheless, the RCA adjustment still reduced the scatter significantly.

Because much of the precipitation was convective in May, underestimation at long ranges was no longer the dominant feature of the unadjusted-radar scatter plots. Even in this largely convective month, the improvement by RCA was evident.

The statistical results including linear correlation coefficient (CC), root mean square error (RSME), and their improvements are listed in Tables 3 and 4. The margin of improvement, shown in brackets, is with respect to the CC and RMSE of the original DPA, and quantifies the improvement brought by RCA adjustment. In Table 3, CC values with RCA adjustment are always greater than those before RCA adjustment. The improvement in CC is over 10% in all months except May. This is similar to the result (10%) of 46-h storm total precipitation of KRTX case (Portland, Oregon) in Seo et al. (2000). For April, as noted above, the relatively poor quality of radar data (due to AP contamination) decreased the CC to rather small values. Even after the RCA adjustment, CC is only 0.39. As such, the improvement of 25.5% may not be taken seriously. In May, the improvement of RCA adjustment is smaller (only 7.5%) due to convective precipitation. Note that the prototype RCA algorithm is developed for stratiform rain events (Seo et al., 2000). To handle embedded convection, RCA will be supported by the Convective-Stratiform Separation Algorithm (CSSA) in operational implementation, which is currently under development (Seo et al. 2002).

The RMSE values in Table 4 also indicate that RCA adjustment yields consistently smaller errors in 24-h precipitation. The degradation in RCA performance for convective rain events is also reflected in the RSME values

Table 3. Linear correlation coefficient (CC) values and their improvements based on the original DPA (number in the bracket) in each month.

Month	CC value and improvement (%)	
	Original	RCA-adjusted
Feb.	0.65	0.76 (17.6%)
Mar.	0.71	0.80 (12.2%)
Apr.	0.31	0.39 (25.5%)
May	0.60	0.65 (7.5%)

Table 4. Root-mean squared error (RMSE) values and their improvements based on the original DPA (number in the bracket) in each month. MB-adjusted represents with mean-field bias (MB) adjustment.

Month	RMSE value (mm) and improvement (%)			
	Orig.	MB-adj.	RCA-adj.	MB & RCA-adj.
Feb.	10.67	12.1 (-13.8%)	9.9 (6.9%)	9.6 (10.3%)
Mar.	9.94	9.94 (-3.7%)	9.6 (3.0%)	8.3 (16.4%)
Apr.	9.03	8.9 (1.3%)	8.7 (3.4%)	7.5 (16.5%)
May	9.83	11.7 (-18.7%)	9.2 (6.4%)	9.7 (1.1%)

4. CONCLUSIONS

A four-month validation using KLWX real-time data (February through May of 2003) indicates that the RCA algorithm consistently improves radar rainfall estimates. It is noted here that, over the validation period, the prototype RCA was under development and minor changes were made to the code and to the adaptable parameters. Even under this less-than-ideal situation, the improvement is significant in both radar-only evaluation and gauge-radar evaluation. Gauge-radar evaluation shows that the improvement in 24-h precipitation is more than 10% for the correlation coefficient and root mean square error criteria.

It was found that two factors affected the performance of the prototype RCA most significantly; the quality of radar reflectivity data (AP contamination in particular) and embedded convection. With respect to data quality, the expectation is that the implementation of the Enhanced Pre-processing (EPRE) algorithm and the Radar Echo Classifier (REC) algorithm will provide RCA with consistently high-quality reflectivity data. With respect to convection, the prototype Convective-Stratiform Separation Algorithm (CSSA, Seo et al. 2002) should be matured and implemented to support RCA under the 'stratify-and-adjust' strategy.

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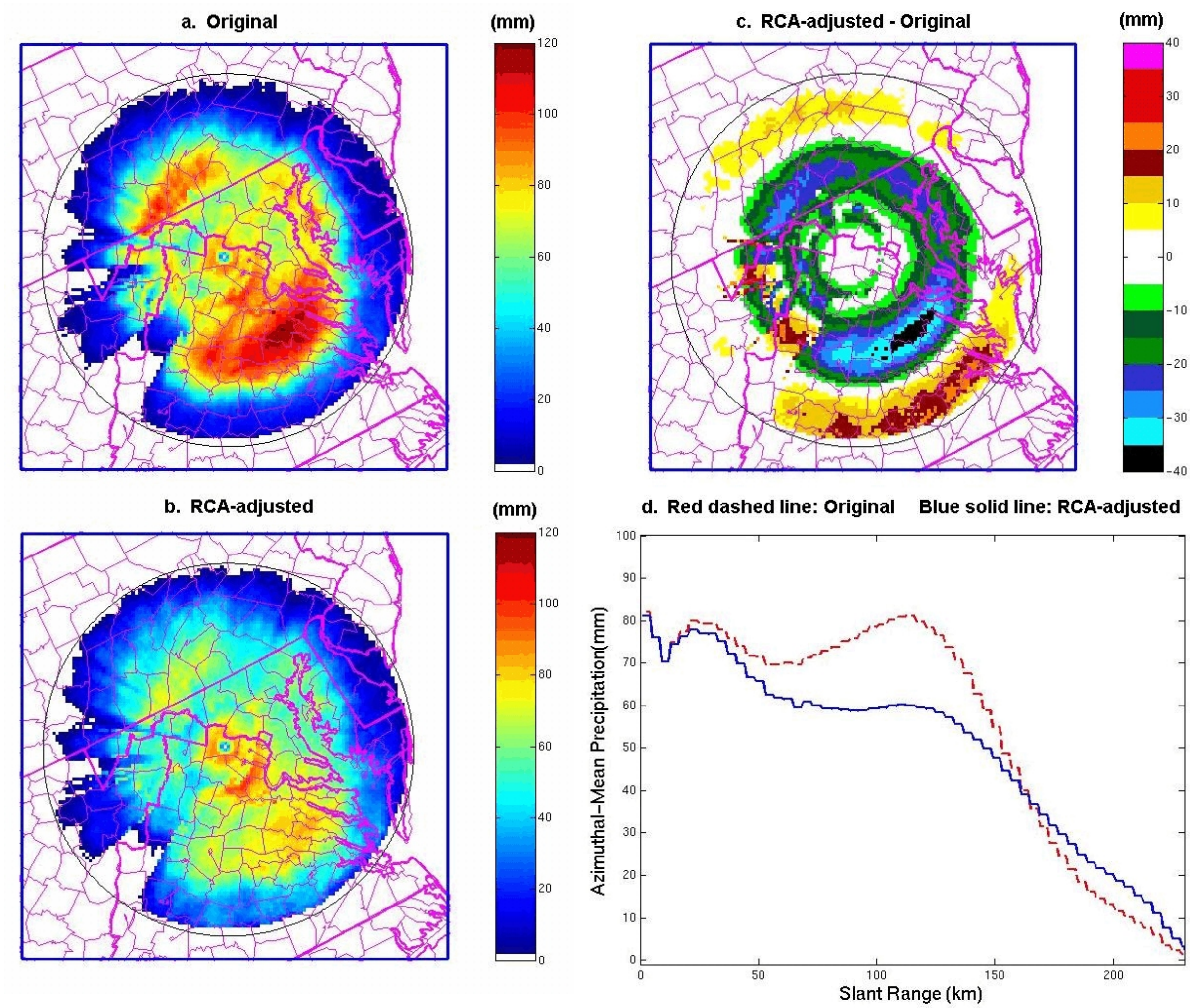

Figure 1. Radar precipitation accumulations from (a) the original DPA, (b) DPA with RCA adjustment, (c) difference of precipitation accumulations between the original and with RCA adjustment, and (d) azimuthal averages of precipitation accumulations from the original (red dashed line) and with RCA adjustment (blue solid line), in March 2003.

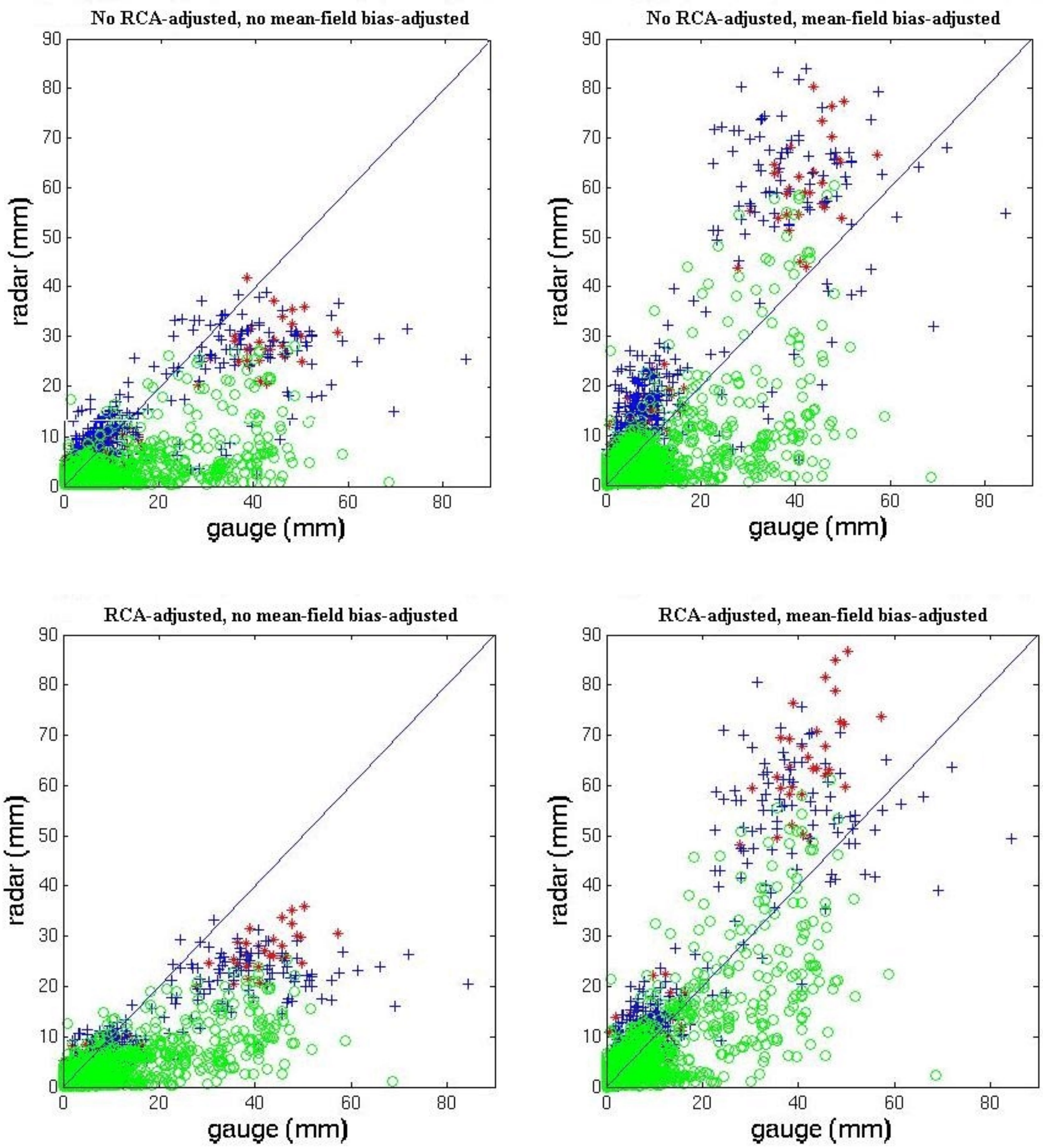

Figure 2. Scatter plots of 24-h precipitation, gauge vs. radar, in March 2003 (red stars from near-range; blue crosses from mid-range; green circles from far-range).