P2B.7 **TRUNCATION ERRORS IN HISTORICAL WSR-88D RAINFALL PRODUCTS**

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1. INTRODUCTION

The National Weather Service (NWS) WSR-88D radars host a number of complex scientific algorithms that produce value-added radar products for our customers, including precipitation products of various durations in digital and graphical formats from the Precipitation Processing System (PPS; Fulton et al. 1998). Recent detailed analyses of these rainfall products have uncovered a small and very subtle software error, which we will call the "truncation error," that has been latent in the radar software since the radars were first deployed over 10 years ago.

The impact of the truncation error on the rainfall products generated in legacy Radar Product Generator (RPG) Software Builds 10 and prior has been non-trivial in certain circumstances, particularly stratiform rainfall events, and may largely explain the long-known tendency for the PPS to underestimate rainfall in these situations.

2. DESCRIPTION OF THE ERROR

All algorithms resident on the WSR-88D, including the PPS, were developed and coded in the FORTRAN computer language in the mid-late 1980s by the NEXRAD contractor based upon government specifications. To improve efficiency of algorithm execution (an important factor during those times), the contractor implemented the algorithms using primarily integer-based mathematics and appropriate scaling factors to represent real numbers. At one stage in the calculations, scan-to-scan accumulations, based upon mean scaled-integer rain rates, were inadvertently truncated rather than rounded to the existing PPS internal data precision of 0.1 mm = 0.004 in. When an explanation for the tendency of the PPS to underestimate rainfall was first being investigated, this software feature was thought to be an inconsequential and trivial oversight. But upon detailed analyses of products before and after the fix, it was realized that this truncation could have a cumulative effect that could sometimes result in rather substantial underestimation of rainfall amounts and areal rainfall coverage. The degree of underestimation was found to vary from situation to situation, being most pronounced for prolonged light rain events and least pronounced for events characterized by short-duration heavy downpours. Additional information describing the truncation error in greater detail can be found in Seo et al. (2000) and Fulton et al. (2001).

It was necessary to correct the software deficiency in three phases in three different WSR-88D software releases, first by implementing proper rounding in the code and imposing a very low rainfall threshold (what we will call the "simple fix with filter", SFIX), second by enhancing the PPS code to perform simpler addition of scan-to-scan accumulations instead of both addition and subtraction (and thus alleviating the need for the previously-imposed low rainfall filter) (what we will call the "enhanced fix", EFIX), and third to resolve rainfall at a 10-times-higher internal data resolution of 0.01 mm (the "final fix", FFIX).

The first change, implemented in Open RPG (ORPG) Software Build 1, resulted in the most significant improvements to the rainfall estimates, while the second change, implemented in ORPG Build 3, provided a smaller measure of improvement. The third and final correction of the error, to be implemented in ORPG Build 4, has not yet been fully and statistically evaluated over many events and will not be reported here. Build 1 was deployed across the U.S. primarily in the April-July 2002 time frame, Build 3 primarily in the April-July 2003 time frame, and Build 4 will be delivered nationwide around October-December 2003. The detailed delivery schedule for these software builds to each WSR-88D radar can be found at the NWS Radar Operations Center web site http://www.roc.noaa.gov/ssb/cm/csw_notes/compsw.asp. For historical case study analyses using PPS products, these delivery schedules can be used to determine whether the products are from before or after each of the three software fixes.

3. SAMPLE DATA

Seo et al. (2002) described the results of a quantitative study of the impacts of the first software change (SFIX) to the PPS software in ORPG Build 1. This paper extends that analysis to include the impacts of the second truncation fix in ORPG Build 3 (EFIX). A future paper will describe the quantitative impacts of the final ORPG Build 4 fix. The sample data are hourly Digital Precipitation Array (DPA) products (approximately 4 km grids) from the Sterling, Virginia WSR-88D radar (KLWX) and cover the months of July 2001 and December 2001 through February 2002. These months represent times when operational KLWX DPAs were archived at the Hydrology Lab and readily available. There are 115 hours of DPA products with positive rain, of which 78 hours are from stratiform rain events and 37 hours are from convective rain events. The precipitation type was determined subjectively by visual examination of the rainfall images and

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determination of the dominant precipitation type for each event. The type of rainfall event is relevant here because our analyses have shown that the amount of truncation depends in part on the rainfall intensity, and typically convective (stratiform) events are dominated by high (low) rain rates. Many events we have examined have continuous rainfall lasting for over 10 hours. All DPA products examined have valid ending times at the top of the hour. The DPA data containing the precipitation truncation errors (hereafter referred to as NOFIX DPA data) were collected from the KLWX radar running the legacy RPG Build 10 software. The DPA data with the "simple fix with filter" correction (SFIX DPA data) were obtained by replaying the corresponding Archive Level II base data using ORPG Build 1 software on our off-line ORPG system with identical parameter settings. The DPA data with the "enhanced fix" correction (EFIX DPA data) were obtained by replaying the same base data using our ORPG Build 3 system.

4. STATISTICAL RESULTS

The statistical analyses are performed separately for the two different types of precipitation events and then for the combined ensemble dataset. A grid point is counted as a sample grid point only when it is classified as one with rain in either the NOFIX, SFIX or EFIX DPA data. In all statistical computations, the SFIX or EFIX DPA data are considered as the true value relative to the NOFIX data. The rain volume is defined as the product of depth and area of rainfall in units of km^3.

In Seo et al. (2000), it was stated that the net impact of the precipitation truncation problem on the DPA product was that accumulations after the first hour will be underestimated by, on average, 1.5 to 2.0 mm per hour for all hourly-based products, and the effect is cumulative, i.e., the running-hourly-total accumulations will be diminished by an *additional* 1.5 to 2.0 mm for each hour that rain continues steadily. Thus the rate of loss of hourly rainfall increases with time within a given event.

Before the statistical computations were performed, SFIX, EFIX, and NOFIX DPA data were displayed to visually illustrate the impact of the truncation problem. Figures 1 and 2 show the NOFIX, SFIX, and EFIX DPA hourly rainfall images for one chosen hour in a long-lasting stratiform and a convective precipitation event, respectively. The three panels in Fig. 1 show significant differences. The SFIX and EFIX DPA data are relatively similar, but both fixes show over 300% larger rain areas (94272 km^2 and 98112 km^2, where rain area is computed from all pixels with positive rainfall) than the corresponding NOFIX DPA data (29696 km^2) for this case. Rounding in Build 1 instead of truncation caused many more new rainy pixels to appear in the DPA products that were previously undetected. And the subsequent removal of the low-rainfall filter in Build 3 then caused 4% more positive rainfall pixels to appear around the edges of the rain areas. The maximum hourly point rainfall amount in SFIX (10.3 mm) and EFIX DPA (10.3 mm) for this stratiform case are also significantly greater than that in NOFIX DPA (6.5 mm) by almost 160%.

Figure 2 illustrates that the truncation problem manifested itself in convective precipitation events as well; however, it is not nearly as serious as that in stratiform events. The rainfall areas in the NOFIX, SFIX, and EFIX cases are 35536, 45712, 49936 km^2 respectively indicating that the SFIX (EFIX) has 30% (40%) larger area than the NOFIX case for this one hour, not insignificant but much less different than for the stratiform event in Fig. 1. The corresponding maximum hourly rainfall accumulations in the three cases are relatively similar: 59.6, 61.3, and 61.3 mm respectively.

Table 1 presents ensemble statistical results of hourly rainfall depth and volume which are computed by using all sample data for both types of precipitation. Shown are mean error (ME), root mean square error (RMSE), and rain volume (RV). The error is the difference of SFIX or EFIX DPA data and NOFIX DPA data at the same grid point and the same time.

Table 1. The ensemble hourly statistical results.

Rain type	ME (mm)		RMSE (mm)	
	SFIX	EFIX	SFIX	EFIX
stratiform	1.10	1.10	1.44	1.41
convective	0.60	0.65	0.84	0.84

Rain type	RV (km^3)			RV-DIF (EFIX, SFIX)(%)
	NOFIX	SFIX	EFIX	
stratiform	1.415	5.760	5.774	0.25
convective	1.544	1.851	1.873	1.26

In SFIX and EFIX DPA data, both stratiform and convective precipitation show positive ME values as expected. However, the magnitudes of ME and RMSE for the stratiform precipitation are much greater than those for the convective precipitation. Again, the impact of truncation problem is much more serious in the stratiform events than in the convective ones.

The ensemble rain volumes (RV) in Table 1 exhibit similar results and reinforce the conclusions derived from Figs. 1 and 2. They show that the EFIX enhancement incrementally increases the rainfall volumes but not nearly as much as the increase in going from NOFIX to SFIX. To quantitatively compare the difference of truncation corrections between SFIX and EFIX, RV-DIF, which is defined as $(RV_{EFIX} - RV_{SFIX})/RV_{SFIX}$, is computed and listed in Table 1. For the two types of precipitation, the values of RV-DIF are very small. SFIX corrects the large majority of truncated rainfall while EFIX corrects a small additional amount, particularly for very light rainfall. It is expected that the Build 4 changes will also result in small incremental, though not substantial, quantitative improvements.

Finally, the total accumulated rainfall amounts of all the stratiform precipitation events, all the convective precipitation events, and all the precipitation events together from NOFIX, SFIX, and EFIX DPA sample data are shown in Fig. 3. The maximum point total rainfall accumulations in the stratiform SFIX and EFIX data over the period of study are about 250% larger than the NOFIX data, while the difference is a smaller but not insignificant 120% factor of underestimation for the ensemble convective data. From these panels, it can be seen that the monthly, seasonal, and overall truncated rainfall amounts could be in ranges of 1 to 3 inches over large areas. The potentially significant impact of the truncation problem on the long-term rainfall estimates is evident in this data.

5. SUMMARY AND CONCLUSIONS

A small but consequential software programming truncation error in the WSR-88D's PPS rainfall algorithm has been recently discovered and partially corrected in a two-phased enhancement to the WSR-88D baseline software in ORPG Builds 1 and 3. This error has been causing a non-trivial reduction in rainfall amounts and areal coverage with a magnitude that depends in part on the rainfall intensity such that greater underestimation of accumulation and area occurs for light stratiform events than intense convective events. The total rainfall volume (area X depth) for the sample of stratiform events we examined was underestimated by a non-trivial factor of about 4, while the convective event rain volume was underdone by a lesser factor of about 1.2 (see Table 1). Unfortunately this error impacts the entire NWS historical record of WSR-88D precipitation products (including the DPAs) from the early 1990s up until 2003, including value-added products derived from DPAs such as the regionally-mosaicked RFC Stage III (radar + gauge) hourly precipitation products (Fulton et al. 1998). The impact on the Stage III products is likely not quite as large because of Stage III's use of real-time rain gauge data for calibration of the radar estimates, but even rain gauge data will likely not fully correct such errors (especially lack-of-detection errors), leaving residual truncation-related radar errors even in the Stage III multisensor rainfall products. Users of these PPS and Stage III products should be aware of this product deficiency if attempting to use them for quantitative purposes, especially products from stratiform events with light rain rates. Unfortunately a simple and accurate correction to past products is not possible without retrospectively rerunning the PPS from base data which would not be a trivial task for other than limited case studies.

6. REFERENCES

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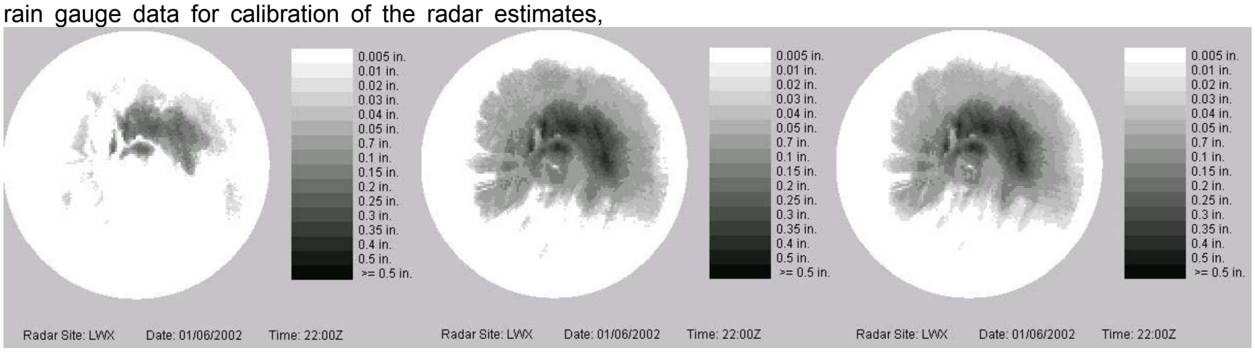

Figure 1. One-hour DPA rainfall from NOFIX (left), SFIX (middle), and EFIX (right) for a stratiform precipitation event (2100-2200 UTC 1/6/2002) 12 hours after the start of the event at KLWX.

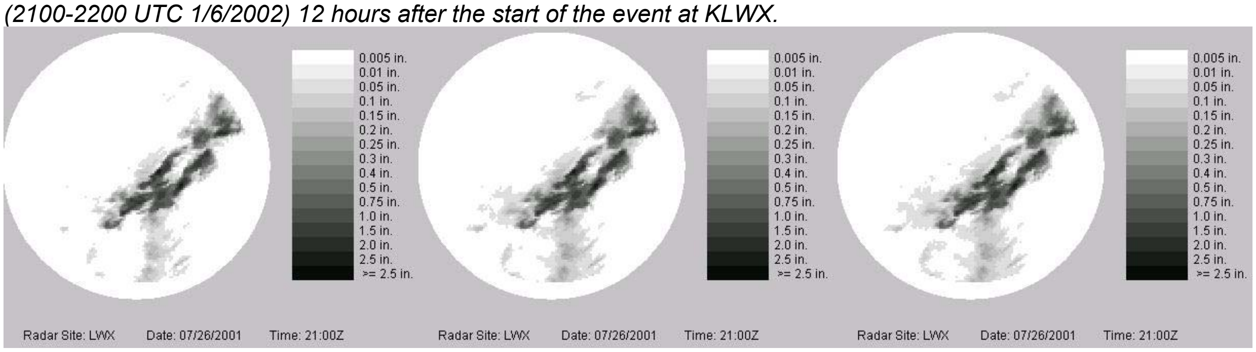

Figure 2. Same as Fig. 1 but for a convective precipitation event at KLWX (2000-2100 UTC 7/26/2001)

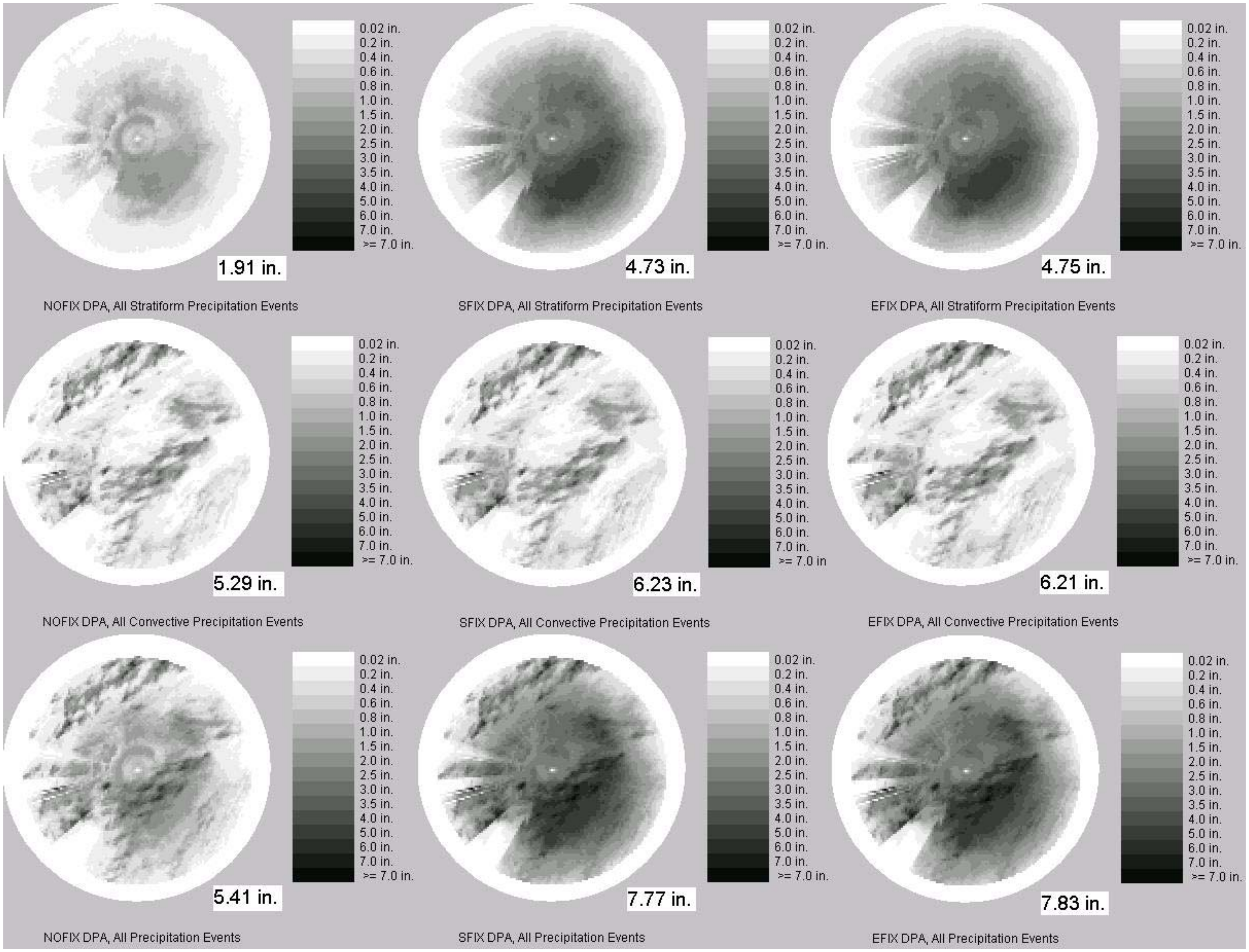

Figure 3. Total rainfall amounts of all the stratiform precipitation events (top), all the convective precipitation events (middle), and all the precipitation events (bottom) from NOFIX DPA (left), SFIX DPA (middle), and EFIX DPA (right). The maximum value is shown in the lower right corner.