3. Precipitation Truncation Problem in the WSR-88D PPS Algorithm: Description, Quantification and Ramifications

3.1 Background

It has been known for some time that the WSR-88D PPS algorithm truncates very light precipitation amounts. Due to precision restrictions inherent in the design of the PPS code, instantaneous precipitation rates less than ~0.6 mm/hr (when in VCP 11) or ~0.5 mm/hr (when in VCP 21) are lost while accumulations in the 5 to 6-minute volume scan-to-volume scan periods are being summed. Even if precipitation were to be sustained just at or below this rate (which corresponds to ~21 dBZ with the Default settings of the Z-R parameters) for a prolonged period, at worst ~.024" would be lost per hour, and more likely, less. This, typically, would not substantially affect quantitative accumulations generated by the PPS, particularly because, under slightly different circumstances (e.g., precipitation just exceeding the above-stated rates), the PPS code would slightly overestimate accumulations by an equivalent amount.

However, reports continued to be received periodically that indicated the problem might be more serious than suspected. Dave Kingsmill of the Desert Research Institute (DRI)[1] recently asserted[2] that rainfall rates less than 2 mm/hr (~.08"/hr) were not being tallied (corresponding to an equivalent reflectivity of 29 dBZ with the Default Z-R relationship). Curt Hartzell and Arlin Super reported that they got improved results in their work on (an off-line version of) the WSR-88D-based Snow Algorithm (Super and Holroyd, 1998) if they lowered the reflectivity at which they could record precipitation from 22 to 4 dBZ (Hartzell and Super, 2000). And while the case studies on South Texas extreme rainfall events discussed in Section 2 of this document were being undertaken, it was at times suspected that the PPS algorithm was under-accumulating precipitation. This was based upon the high frequency of occurrence of radar sample bins registering no hourly precipitation coincident with hourly gage reports of measurable amounts, and the occasional observation of zero or near zero accumulations in areas of the 16-level, one-hour accumulation products where reflectivity levels would seem to have supported greater amounts.

3.2 Truncation Problem Explained

In response to the above concerns, an in-depth examination of the code of the Rate/Accumulation algorithm-task was undertaken together with evaluation of detailed diagnostics. This culminated in the discovery of a second, more serious problem pertaining to precipitation truncation - a consequence of a family of simple coding errors. In several instances when accumulations in the 5- to 6-minute scan-to-scan periods are being determined (from the instantaneous precipitation rate within the period-scan and the fractional duration of the period within the hour), intermediate, real results are truncated, rather than rounded, when stored (to the nearest .1mm) in Integer*2 arrays. This is not a matter which is at play only when rainfall rates are very light (as is the case with the first issue, discussed in Section 3.1); rather, it is a matter which is at play whenever measurable precipitation is occurring. Although the effect in any given instance may seem trivial - only a 50% chance that .1 mm will be lost - the cumulative effect can be quite significant. The degree to which this is a problem depends on the number of instances of potential truncation occurring in the code during the formulation of a particular PPS product, and the nature and duration of the precipitation event. The longer lasting and steadier an event (i.e., the greater the percentage of volume scans in which it is raining at any given gridpoint), the more serious will be the quantitative impact; the lighter the precipitation rate (as long as it is measurable), the greater will be the relative impact.

3.2.1 Impact on Storm Total Precipitation (STP) Product

In the STP product, precipitation totals are formulated at each gridpoint by summing the rainfall amounts in each 5- to 6- minute scan-to-scan period for the duration of the event, or (if presently raining), from the time of onset of the event until the current time. Therefore, there is one instance in the code for each period-scan when, due to the above-mentioned coding effect, accumulation may be underestimated by .1 mm (50% chance), as long as it is "raining" at that gridpoint at that time[2]. Thus, during steady rainfall, accumulations will be underestimated by an average of .5 mm (.020") every hour when operating in VCP 21, and by an average of .6 mm (.024") when in VCP 11. The impact of this truncation problem will thus be very dependent on the duration and intensity of the precipitation. For example (assuming rainfall every volume scan and VCP 21), if 50 mm were to fall in two hours at a given gridpoint, an average of 1 mm would be lost (2%); on the other hand, if the same 50 mm were to fall in 24 hours, an average of 12 mm would be lost (24%).

Figure 3.1 depicts Storm Total products and differences through a nine-hour, mostly-steady rainfall event (Twin Lakes, OK, 04/26-27/98 ending ~03 UTC). The upper left panel shows the STP product with the Truncation errors; the upper right shows the same from a Prototype version of the PPS algorithm[3] in which all known instances of truncation have been Corrected to rounding (to the nearest .1mm in the 5- to 6-minute period accumulation scans); the lower left shows the Differences by amount; the lower right, the Differences by percentage (((Corrected - Truncated)/ Truncated) x 100).

Note that the versions of the STP product with the Truncation problem and with the problem Corrected appear quite similar at first glance. Examination of the two Difference images in the lower panels (which are also valid at 4/27/98 3:05 UTC) reveals that some non-trivial variations exist (e.g, in the 3-6 mm range in regions where storm totals are 35 mm or greater). The event, itself, shows a marked range degradation (either due to where rainfall actually occurred or to overshooting). Differences by amount are positively correlated with the amount of rain. This correlation, however, is actually directly related to the number of volume scans during the entire event in which measurable rainfall occurred (at the rate of at least .05 mm/hr). Differences by percentage are seen, in general, to be inversely related to storm totals. This appears particularly dramatic around the edges, where percentage differences are very high but accumulations, themselves, are very small. (It should be noted that, had these differences been referenced to the higher accumulations, - i.e. (((corrected - truncated)/ corrected) x 100), they would not have appeared as dramatic.)

3.2.2 Impact on Hourly-based Products (OHP; THP; USP; DPA)

Hourly accumulations in products such as One Hour Precip (OHP) and Hourly Digital Precipitation Array (DPA) are formulated separately from storm total accumulations in the PPS code, and accumulations in the multi-hour products (e.g., Three Hour Precip (THP) and User Selectable Precip (USP)) are determined by summing the totals in consecutive "clock hours" (i.e., hours ending exactly at the "top of an hour"). During the first hour following the onset of a precipitation event, hourly accumulations are determined in the same manner as storm total accumulations and therefore, rainfall totals will be underestimated by ~.5 mm (on average), if it is raining every volume scan during that hour. Thereafter, hourly accumulations are updated by adding to a running-hourly-total gridfield the amounts in the newest period-scan, and subtracting out the amounts in period-scans phased out of the hour. The number of period-scans involved in each calculation is between two and four because fractions of period scans are processed, as well as full period scans, in order to assure that the accumulation period is exactly an hour, including once per hour when the accumulation period begins and ends exactly at the top of an hour. Each of these instances provides a 50% chance that underestimation by .1 mm will occur, due to the above-described coding anomaly. The net effect is that, after the first hour, accumulations will be underestimated by, on average, 1.5 to 2.0 mm per hour in all the hourly-based accumulation products. What's more, the effect is cumulative: the running-hourly-total gridfield will be diminished by an additional 1.5 to 2.0 mm/hr for each hour that rain continues steadily. In essence, the hourly products are "leaking away" precipitation.

As a hypothetical example, if a given gridpoint begins an hour with 20.0 mm of accumulated rainfall and if it had rained 10.0 mm in the previous hour and continues to rain 10.0 mm during the present hour (and measurable rainfall occurs every volume scan of both hours), that gridpoint should end the hour still registering 20.0 mm of accumulated rainfall (i.e., 10.0 mm added in replaces 10.0 mm phased out). Instead, due to the "truncation error" in the code, that gridpoint may register only 8.0 to 8.5 mm at the end of the hour. For each hour that this situation were to persist, the rainfall deficit would become exacerbated, perhaps eventually resulting in the hourly rainfall total at the point in question "zeroing out" (e.g., some 5 - 6 hours later), when it still should be 10.0 mm. (Note that the running-hourly accumulations are prevented from becoming negative by a bottom "floor" of zero in the code.)

The impact of this coding anomaly is, thus, potentially far more serious on the hourly-based products than on the Storm Total product, and becomes increasingly severe the longer a steady precipitation event lasts. An illustration of this is shown in Figs. 3.2-1 and 3.2-2. Each figure shows a one-hourly accumulation from the existing PPS algorithm (i.e., with the Truncation Problem) in the upper left panel; the accumulation for the same hourly period from the Prototype algorithm version (i.e., with the truncation problem Corrected) in the upper right panel; their difference, by amount, in the lower left panel; and their difference, by percent, in the lower right panel. The first figure captures the first hour of a steady precipitation event (i.e., Twin Lakes, OK, ending 4/26/98 ~19 UTC), while the second figure captures the ninth hour (i.e., ending 4/27/98 ~03 UTC).

In Fig. 3.2-1 the two upper panels appear quite similar, particularly in regions where the accumulation is greater than 1 mm, and the differences are almost indiscernible (at the 16-level resolution of the presentation) in regions where amounts are greater than 6 mm. The lower left panel does reveal a precipitation deficit just about wherever it was raining, though of less than 1 mm. Since the deficit is nearly uniform, its relative impact is inversely proportional to accumulation amounts. This can be seen in the lower right panel, such as around the periphery of the main precipitation area to the north of the radar (where accumulations are less than 1 mm and differences may exceed 40%) and, conversely, along some narrow lines to the southwest of the radar (where accumulations exceed 15 mm and differences are less than 10%). Overall, it is seen that early in an event such as this, the impact of the Truncation Anomaly on the hourly accumulation products is relatively minor.

In Fig. 3.2-2, however, very significant differences are apparent between the hourly accumulation products with and without the Truncation problem (i.e., two upper panels), and differences are seen in the lower left panel that are comparable in coverage area and magnitude to the products themselves. Percentage differences are seen in the lower right panel to generally be greater than they were one hour into the event, but again, these differences are relatively smallest where hourly accumulations are greatest, such as to the southeast of the radar where recent heavy rains fell and differences are less than 10%. But in other locations where comparable amounts fell in the past hour (as seen in the Corrected product), such as to the north and northeast of the radar, precipitation deficits are much greater. The distinction between these two regions is that to the north and northeast, sustained rainfall had occurred for several hours, whereas to the southeast, significant rainfall had just recently begun. Thus, it is born out that the longer precipitation is sustained at a given location, the greater will be the impact of the Truncation Anomaly on the hourly-based products.

3.3 Another Look at the 1998 South Texas Extreme Precipitation Events

In order to determine the qualitative and quantitative effects of the Truncation Problem on some significant cases, several of the previously-run test simulations of the extremely-heavy South Texas rainfall events of August 21-24 and October 17-19 '98 (discussed in Section 2) were repeated with the Prototype, Corrected version of the PPS algorithm (described in 3.2.1). Specifically, the simulations from the Houston (HGX) radar for both the August and October events performed with each of the 'Default' and 'Tropical' Z-R relationships (and the Hail Cap unchanged) were rerun. Details of the methodology used in these test runs and analyses can be found in Section 2.3.

3.3.1 Default Z-R Simulations

An overview of the results of the cases rerun with the Default Z-R parameters for the HGX August and October events can be found in Figs. 3.3A.H and 3.3O.H, respectively. (For details of the format and content of these overview figures, see Section 2.4.1.) These results should be compared directly to those in Figs. 2.4A.H and 2.4O.H for the analogous runs from the Original PPS algorithm version.

3.3.1a: Evaluation of Effect on Hourly Accumulation Products

The differences in the one-hour G-R analyses (left-hand columns of figures) are seen to be far more dramatic than those in the 24-hour G-R analyses (right-hand columns). While both the August and October events witnessed some very heavy local downpours, they also both saw sustained precipitation in some locales for many hours (particularly the October event), so it would not be unexpected to observe substantial differences in the Corrected vs. Uncorrected hourly products, based on the nature of the Truncation Problem (discussed above). In the one hour products for a typical hour seen in the upper left panels, the differences in coverage area (i.e., some vs. no accumulation) are particularly noticeable, and significant discrepancies are observed at light accumulation levels (i.e., up to 3 mm). There are even some areas where accumulations were up to 3-6 mm in the Corrected runs but had "zeroed out" in the Original runs (particularly in the October event). Only in regions which experienced recent downpours (as can be discerned from the reflectivity images displayed in Figures 2.3A.H and 2.3O.H) and which now exhibit the heavier accumulation amounts (e.g., >10 mm) are very small differences observed between the Original and Corrected products.

The differences, statistically, over the course of multiple hours of the One-Hour G-R analyses are seen in the lower left panels. Biases are reduced dramatically from the Uncorrected to the Corrected runs (2.04 to 1.40 for the August case; 3.55 to 2.15 for the October case). Indeed, these reductions are comparable to those obtained when going from the Default to the Tropical Z-R relationship while retaining the Original algorithm version (2.04 to 1.13; 3.55 to 1.81). The RMS errors are, likewise, significantly reduced when going from the Uncorrected to the Corrected runs (3.87 to 2.87 for August; 15.43 to 10.88 for October) and the correlation coefficients are improved (.52 to .62; .74 to .79). (Note: for a more direct, statistical comparison of the Original vs. Corrected algorithm simulations for all the cases rerun, see Tables 3.1A and 3.1O.)

One of the most striking dissimilarities between the Uncorrected and Corrected runs pertains to a phenomenon first discussed in Section 2.5.2: due to the significant increase in radar sample bins co-located with rain gages able to register measurable hourly accumulation (at the precision of the algorithm), a substantial augmentation in the number of qualifying G-R Pairs is witnessed in the Corrected-algorithm runs. This number rises from 197 to 297 (51%) in the August event and from 345 to 610 (77%) in the October event! Indeed, almost all of the non-zero gage reports at individual hours are now matched with non-zero radar values. One consequence of this, though, is that the light precipitation amounts contained in these added G-R Pairs cause the Mean Gage computation to be reduced considerably (e.g. from 11.54 to 7.98 mm in the October event), and diminish the amount by which the Mean Radar value would otherwise have risen (e.g., 3.25 to 3.71 in October), had the calculation included only the original G-R Pairs. Curiously, though, these added G-R Pairs ultimately had very little effect on Bias calculations: when they were redetermined for the Revised-algorithm runs including only the original G-R pairs, they were found to be nearly identical to those determined when all G-R Pairs were included, for both events (more on this in Section 3.4, below).

3.3.1b: Evaluation of Effect on Storm Total Precipitation Products

The 24-hour STP products for the two cases are shown in the upper right panels of Figs.

3.3A.H and 3.3O.H (Corrected) and 2.4A.H and 2.4O.H (Uncorrected). It is seen that the differences between the Uncorrected and Corrected STP products themselves are not nearly as dramatic as for the One Hour products, but are noticeable upon close examination. Statistically, as seen in the lower right panels, the 24-hour differences are also not as dramatic as the One-hour, but neither are they insignificant. The bias is reduced from 2.34 to 2.00 in the August event and from 2.90 to 2.52 in the October event, while the RMS error is lowered, correspondingly, from 25.59 to 23.90 and from 106.34 to 98.03. Correlation coefficients are slightly increased in both instances.

Due to the much longer period of accumulation, the phenomenon of a great enhancement in the number of qualifying G-R pairs that was seen in the one-hour analyses is barely observed in the 24-hour analyses. For the August event, that number remains the same (at 45); for the October event, it increases slightly (from 38 to 41).

3.3.2 Tropical Z-R simulations

An overview of the results from the cases rerun with the Revised PPS algorithm and the Tropical Z-R settings for the HGX August and October events can be found in Figs. 3.4A.H and 3.4O.H, respectively. These results should be compared directly to those in Figs. 2.5A.H and 2.5O.H for the Tropical Z-R runs from the Original algorithm version.

3.3.2a: Evaluation of Effect on Hourly Accumulation Products

As when the Default Z-R runs were compared, the differences between the Tropical runs manifested in the Hourly G-R analyses are quite substantial. In the OHP products for a typical hour (upper left panels), the area covered by measurable precipitation is again seen to be significantly enlarged, while little differences are observed in the locally heavy precipitation regions. Comparing the statistics (lower left panels), the bias in the August event is seen to go from slightly greater than one (1.13) to less than one (0.88). In the October event, it still exceeds unity but is reduced significantly (from 1.81 to 1.32). RMS errors are again reduced significantly (3.95 to 3.33, August; 11.48 to 8.35, October), and correlation coefficients are notably improved (.56 to .63; .75 to .80). The number of qualifying G-R Pairs also increases substantially (216 to 302 (up 40%), August; 396 to 613 (up 55%), October).

3.3.2b: Evaluation of Effect on Storm Total Precipitation Products

Differences between the Uncorrected and Corrected 24-hour G-R analyses are more modest. Only upon close examination can some slight variations be discerned in the 24-hour STP products (upper right panels). Non-trivial differences are revealed, however, in the 24-hour statistics (lower right panels). The bias is reduced from 1.30 to 1.17 in the August event and from 1.62 to 1.50 in October. RMS errors are also lowered (19.79 to 18.70, August; 73.09 to 69.28, October) while correlation coefficients and the number of qualifying G-R Pairs remain about the same.

3.4 Differences Between Uncorrected and Corrected Algorithm Versions Further Quantified

In order to further quantify the effects of the Truncation Problem on the PPS products, the results of the runs with the Prototype algorithm were re-analyzed using only the same G-R Pairs as in the Original runs. These results are shown in Tables 3.1A and 3.1O as the parenthesized values under the first results in the "Corrected Algorithm" columns. The corresponding results from the runs with the Default version of the PPS algorithm are shown in the adjacent "Original Algorithm" columns, to the left. The radar accumulations from these two sets of G-R Pairs constitute an independent subset of sample bins where measurable rainfall had occurred that allow, in each test scenario, for a direct comparison of Corrected vs. Uncorrected results. With the Prototype algorithm results being considered "ground truth" for the purposes of this discussion, the amounts by which radar accumulations have been underestimated due to the Truncation Problem are shown as the parenthesized values beneath the "Mean Radar" entries under the "Original Algorithm" columns.

It is seen that in the Default Z-R simulations, the impact of the Truncation Problem on the Hourly-based products over the integrated duration of the simulations was substantial: a reduction in the Mean Radar value of 33.5% for the August event and 39.0% for the October event. For the Tropical Z-R simulations, the impact on the Hourly-based products was not quite as dramatic but still considerable (25.9% and 28.8%, respectively). The effect of the problem on the 24-hour Storm Total products was less pronounced but still not trivial, with reductions of (14.5%; 13.1%) seen in the Default Z-R simulations and (9.8%; 7.5%) observed in the Tropical Z-R runs. While these findings only pertain, specifically, to the family of radar sample bins with non-zero accumulation coincident with non-zero gage reports, the results can reasonably be inferred to the general Hourly and Storm Total products.

Scatter diagrams were also prepared from these sets of pairs of sample bins from Revised vs. Original algorithm runs (now expanded to include those with zero as well as non-zero radar accumulations, coincident with non-zero gage reports). These are presented for the August and October events in Figures 3.5A and 3.5O, respectively, with Default Z-R results shown in the upper row; Tropical Z-R results shown in the lower row; Hourly accumulations shown in the left column; and 24-Hour accumulations shown in the right column, in each instance.

The slopes of the best-fit lines of these scatter diagrams yield an indication of the mean amount by which the Revised algorithm is accumulating rainfall, compared to the Original. These results corroborate those seen, above, in the difference maps and statistical analyses: that the impact of the Truncation Problem is greater upon the One Hour (and other hourly-based) products than on the Storm Total product. For the Default Z-R runs, the slopes of the one-hourly comparisons (including only non-zero points) are 1.51 (August) and 1.64 (October), while those for the 24-hour STP comparisons are (1.17; 1.15). For the Tropical Z-R simulations, the corresponding slopes are (1.35; 1.40) for the one-hour comparisons and (1.11;1.08) for the 24-hour. From these samples of gridpoints it can thus be interpreted that, over the course of the simulations with the Default Z-R parameters, the Revised algorithm generated over 50% more precipitation than the Original in the Hourly products and over 15% more in the Storm Total products. With the Tropical Z-R settings, the Revised algorithm generated over a third more precipitation than the Original in the Hourly products and over 10% more in the Storm Total products. The fact that the ratios for the One-hour products are universally higher in the October simulations than the August simulations reflects the fact that the rainfall was of a more steady and persistent nature in the October event - a condition which will exacerbate the impact of the Truncation Problem.

For the One-hour products with the Default Z-R settings, the radar vs. radar comparisons were further quantized into groupings: 0 to 2.5 mm; 2.5 to 5.0 mm; 5.0 to 10 mm; and 10+ mm. The scatter diagrams for these groupings for the August and October events are displayed in Figures 3.6A and 3.6O, respectively. Here it is seen that the slopes of the best-fit lines increase sharply as accumulations decrease, reflective of the degree to which the relative impact of the Truncation Problem becomes more pronounced as precipitation rates diminish. At the highest of the four groupings shown (i.e., >10 mm), the slopes are not much different than those seen in the STP products. It can thus be inferred that the relative amount by which precipitation in the Hourly-based products is underestimated due to the Truncation Problem is primarily due to underestimation at the lighter precipitation rates.

3.5 Summary and Conclusions

It had previously been known that, as a consequence of precision restrictions inherent in the design of the PPS code, precipitation occurring at very light rates (e.g., less than ~0.5 mm/hr, or ~21 dBZ) would be truncated and would not contribute to the computation of rainfall totals. The amounts concerned are small, however, and would typically be offset by slight overestimations of rainfall within other ranges of reflectivity (e.g., just above 21 dBZ) so that, overall, this matter would not have a significant bearing on the determination of quantitative precipitation amounts over the course of an event. However, a second, previously unknown problem has been uncovered whereby precipitation amounts may be universally underestimated due to the cumulative effect of slight truncations occurring during the computation of rainfall totals - a consequence of a coding error replicated at several junctures of the code. The quantitative impact of this Truncation Problem or Truncation Anomaly will vary as a function of the PPS product and the nature and duration of the precipitation event, ranging from minor to quite significant:

- Quantitatively, the impact for any given product will be the same whether rainfall rates are light or heavy, as long as measurable precipitation (at the effective precision of the algorithm) is occurring. The amount by which rainfall is underestimated over the period covered by a product will thus be directly proportional to the steadiness of precipitation - i.e., the number of volume scans from beginning to end during which measurable rainfall occurred, at any given point.
- The relative impact will thus be greatest during persistent, light precipitation events and least during heavy events of short duration.
- The problem is potentially more serious in the hourly-based PPS products than in the Storm Total Precipitation (STP) product. This is a consequence of there being

more potential instances of truncation each time the running-hourly total precipitation field (which is the basis of all the hourly products) is updated than when the storm total field is updated. Hourly-based products include One Hour Precipitation (OHP); Three Hour Precipitation (THP); User-Selectable (period) Precipitation (USP); and Hourly Digital Precipitation Array (DPA):

- The STP product will be underestimated by an average of about 0.5 mm (.02") per hour, assuming rainfall every volume scan. If rainfall is sporadic, underestimation will be less.
- During the first hour after onset of a precipitation event, the hourly-based products will be underestimated by an amount comparable to the STP product. Thereafter, they will be underestimated by an average of 1.5 to 2.0 mm (.06 to .08") per hour, during conditions of steady rainfall.
- What's more, the Truncation Problem has a cumulative effect on the hourly-based products; that is, the more hours into a steady precipitation event, the greater will be the rainfall deficit.

- The Truncation Problem could have a significant, quantitative impact on downstream applications that depend upon the (Hourly) DPA product, such as the estimates of rainfall distributed to river basins in the National Weather Service River Forecasting System (NWSRFS), running at the River Forecast Centers (RFCs).
- Other downstream applications that are based upon the Digital Hybrid Scan grid of the PPS, such as the Areal Mean Basin Estimated Rainfall (AMBER) module or the Flash Flood Monitoring and Prediction (FFMP) system, will be unaffected.
- Because of the typically heavy and recent precipitation amounts involved, the Truncation Problem would not generally diminish the usefulness of the PPS graphical products (OHP; THP; STP) as tools for guidance in flash flood forecasting at the Weather Forecast Offices (WFOs).
- Several case studies of extreme, tropical rainfall events that occurred in South Texas during 1998 (discussed in Section 2 of this document) were rerun with a Prototype version of the PPS algorithm that corrects all known instances of the Truncation Problem:
    - The amount by which precipitation totals were underestimated in the runs from the original (operational) PPS algorithm were significantly reduced in the analogous runs from the prototype algorithm. Biases were lowered, RMS errors reduced and correlation coefficients improved.
    - Furthermore, many sample bins coincident with non-zero rain gage reports that had originally registered no accumulation now registered measurable accumulation when rerun with the prototype algorithm.
    - The improvements were substantially greater in the one-hour Gage-Radar analyses (i.e., OHP product) than in the 24-hour analyses (i.e., STP product). This is consistent with the diagnosed nature of the Truncation Problem. In fact, in the one-hour analysis of the simulation run with the Prototype algorithm and Tropical Z-R parameter settings, the Bias became

less than unity (indicating underestimation).

- Based on the results of the runs with the Prototype algorithm and Tropical settings of the Z-R parameters, it would not be deemed necessary that a new "Super Tropical" Z-R relationship be formulated for operational use in cases such as these.

- A revised version of the PPS algorithm will be formulated for implementation in an upcoming build of the Open RPG that will not only correct the errors in the code causing the Truncation Problem (as does the Prototype algorithm used in the above comparison studies), but will also address the issues pertaining to inadequate precision in the PPS algorithm.

[1] Affiliated with the University of Nevada.

[2] Personal communication with members of OH staff.

[3] Note that this Prototype ("Corrected") version of the PPS algorithm is not intended to be the one which, ultimately, will be implemented under an upcoming CCR (to be submitted). That Final version will maintain a precision of at least .01 mm during the period-accumulation scans and thus, approximately .1 mm for hourly accumulations. However, both versions should yield quantitatively similar results, and both will correct the primary problem of underestimation due to Truncation in the present PPS.

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