Final Report to the Radar Operations Center Under Memorandum of Understanding with the Office of Hydrologic Development, 2010-2011

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Executive Summary

Analyses of available dual-polarization and single polarization radar quantitative precipitation estimates from the Norman Oklahoma WSR-88D testbed (KOUN) unit during the period May 2010 to February 2011, and from the Vance Air Force Base (KVNX) unit during March 2011, have been carried out. We have verified one-hour and storm total rainfall estimates from twelve storm events during this period, employing rain gauge data from multiple networks in Oklahoma. Our major findings to date can be summarized as follows:

Modifications to the initially-installed dual-polarization algorithm suite appear to be successful in improving that version’s performance relative to both the rain gauge verification network and the operational NEXRAD Precipitation Processing System (PPS), in terms of statistical measures such as reducing root-mean squared error and increasing correlation relative to rain gauge reports. These modifications include treatment of terrain beam blockage and introduction of a suite of logic-fixes to mitigate the effects of non-uniform beam filling (NBF) and attenuation.

Both the dual-polarization and PPS estimates from KOUN exhibit significant day-to-day variations in gauge-radar bias, and these variations are highly correlated between the two algorithms. An investigation of potential gauge-bias correction methods analogous to those presently implemented within AWIPS was tested. It appears that such bias correction could lead to appreciable improvement in verification scores, relative to the original dual-polarization estimates.
Table of Contents

Executive Summary ................................................................. ii
1. Introduction ............................................................................. 1
2. Task 1.2: Evaluation of dual-polarization precipitation estimates ..... 2
3. Task 1.1: Evaluation Of Real-Time Bias Correction Impacts On
   Dual-Polarization Precipitation Estimates ........................................ 15
4. Evaluation of Non-uniform Beam Filling Correction Algorithm ........ 20
5. General Summary ..................................................................... 22
Acknowledgements ...................................................................... 23
References .................................................................................. 23
1. Introduction

Staff of the Radar Operations Center (ROC), Office of Science and Technology (OST), Office of Hydrologic Development (OHD), and National Severe Storms Laboratory (NSSL) have met routinely and collaborated extensively in evaluating the quality of dual-polarization base data, hydrometeor classification algorithm output, and dual-polarization quantitative precipitation estimates (DPQPE) since early in 2010. Following a number of hardware and Radar Data Acquisition (RDA) system changes, and modifications to DPQPE and its predecessor algorithms, it appears that stable, reliable radar products are being obtained. Assessment of products will continue based on output of the Norman (KOUN) and recently upgraded Vance AFB (KVNX) units in Oklahoma, as well as any other sites upgraded during 2011.

The ROC-OHD agreement for 2010-2011 included two tasks, namely evaluation of possibilities for real-time bias correction for DPQPE (Task 1.1) and evaluation of the quality of the DPQPE itself (Task 1.2). Because more work has been invested in the latter task, and because some of its results are needed to illuminate results of the former task, we treat Task 1.2 first in this report, in Section 2. Results of tests on real-time bias corrections are described in Section 3. Results of a study on the effectiveness of a recently-proposed algorithm for mitigating the effects of attenuation and non-uniform beam filling with hydrometeors are shown in Section 4.
2. Task 1.2: Evaluation of dual-polarization precipitation estimates

Since the initiation of the current Memorandum, OHD staff have analyzed several versions of the evolving DPQPE algorithm, as well as NEXRAD Precipitation Processing System (PPS) estimates. These evaluations are based on radar data from the KOUN and KVNX units and from rain gauge networks in Oklahoma, chiefly the Oklahoma Climate Survey Mesonet; USDA Agriculture Research Service micronets near Ft. Cobb and the Little Washita basin (USDA 2010); and the Oklahoma City micronetwork (University of Oklahoma 2010) (Fig 1).

a. Modifications to original DPQPE and preprocessing algorithms

The originally-deployed version of DP-QPE (i.e. RPG Build 12.0), designated PBB1, applied a strict test on terrain-caused beam blockage. In any sector with blockage \( \geq 1\% \) rain rate estimates were computed from either the horizontal reflectivity moment-enhanced to compensate for partial beam blockage, \( R(Z') \), or – only in bins with heavy rain or hail indicated – from the specific differential phase moment, \( R(Kdp) \). Hence, only in sectors of nearly zero blockage – rare even in flat-terrain locations such as central Oklahoma – would the full family of estimators based on dual polarization moments, including differential reflectivity (i.e. \( R(Z,Zdr) \)), be employed. An enhanced algorithm, designated PBB2, was introduced. The PBB2 takes a more sophisticated approach to handling beam blockage in which different logic paths are taken dependent upon threshold-ranges of blockage (e.g. \( \leq 20\%; 20-70\%; >70\% \)). This methodology relies far more on the dual-polarization moments – particularly \( R(Z,Zdr) \) – and far less on the horizontal reflectivity moment, \( R(Z') \), than does the PBB1 algorithm.

Another potentially serious effect was discovered in which radials passing through intense echoes had unrealistically low horizontal-vertical Correlation Coefficient (CC or \( \rho_{hv} \)), due to the effects of spatially segregated hydrometeor classes within single sample volumes (Jameson 2008), and possibly radio attenuation. The hydrometeor classification algorithm interpreted these values as indicating biota or unclassifiable echoes, resulting in zero precipitation rates in areas that were plainly occupied by hydrometeors, and sometimes heavy rainfall. The preprocessing and Hydrometeor Classification algorithms were modified to restore realistic classifications in sectors that appeared to be shadowed by heavy rain or hail cores. This modification appears to be effective in most instances observed thus far, as explained below in Section 4.

While much data has been collected from the KOUN unit, many cases were judged by ROC, OST, and OHD staff to have poorly-calibrated Zdr, which affects multiple algorithms. Therefore, this analysis is restricted to precipitation events over twelve calendar days on which sustained rainfall occurred for at least a few hours and the Zdr bias was judged to be stable and correctable; static bias correction factors were applied prior to algorithm execution. The Zdr now appears stable and correctable in the KOUN unit and in the KVNX unit, which was upgraded for dual-polarization in February 2011. It should be noted that subjective Zdr bias corrections were factored into the preprocessing and DPQPE algorithms used to obtain the results shown below.
b. Comparative verification results for storm total precipitation: DPQPE and PPS

Several verification statistics were calculated from storm totals for events beginning on the dates shown in Fig. 2. These statistics reflect the effectiveness of the radar algorithms in delineating multi-hour precipitation spatial patterns, with no time dimension.

We noted a significant day-to-day variation in mean field bias values, from around 0.6 to as high as 2.0, shown in Fig. 2. These were based on all nonzero gauge-radar pairs within each multi-hour event, and are simply the sum of the gauge reports divided by the sum of the collocated radar reports. The PPS and DPQPE biases were highly correlated. However, the DPQPE consistently had the same or a smaller bias (relative to the perfect value of 1.0) than did PPS, namely 9 of 11 cases. The potential improvements in correcting these time-dependent biases in real time are explored in Section 3.

The effects of correcting for Zdr bias were apparent for the 24 February 2011 case, in which DPQPE was generated from both corrected and uncorrected Zdr. The position of the square and blue diamond icons shows that without Zdr bias correction, results for DPQPE were poorer than those of the PPS, while with the correction, results were improved.

Similarly, the DPQPE had a higher correlation relative to the gauge storm total values than did PPS. As shown in Fig. 3, the DPQPE linear correlation was higher in eight of the eleven cases.

Finally, the DPQPE had better performance in terms of root-mean squared error (RMSE), as shown in Fig. 4; the fractional RMSE in Fig. 5 contains the results expressed as a fraction of the mean rain gauge amount. These errors were smaller for DPQPE in nine of the eleven events.

c. Comparative verification results for hourly precipitation: DPQPE and PPS

While the results above for storm-total precipitation verification are encouraging, in most hydrologic applications, radar is important because of its ability to detect temporal changes in precipitation rate. To assess the relative value of DPQPE and PPS in terms of spatio-temporal correlation with gauge amounts, we evaluated data from a total of twelve storm cases, involving those described above plus events beginning 25 November 2010 and 31 January 2011. However data from the 8 March 2011 event were not analyzed. Here, all data were from the KOUN radar unit.

A pattern of consistently high correlations for hourly values (Fig. 6) was again evident; all correlations except two were above 0.7, suggesting that there were few unrealistic gauge reports in the overall sample. The DPQPE yielded a higher correlation than did PPS in eight of the twelve storm events, though in some events the difference was very small.

Subsequent analysis is focused on the entire data sample of 4705 1-h estimates, in which the rain gauge and either the DPQPE or PPS algorithms had nonzero precipitation. The large sample enables greater statistical certainty in the comparison.
Within this sample, both sets of radar estimates were biased low and were underdispersed, relative to gauge reports (Figs. 7-8). The mean gauge value was 0.20 inch, compared to ~0.16 inch for the DPQPE and ~0.15 inch for the PPS; the gauge and radar (DPQPE and PPS) standard deviations were 0.34, 0.29 and 0.27 inch, respectively (Fig. 7). Though the precipitation distributions are not Gaussian, the relative size of the standard deviations indicates that the distributions of the radar estimate have an unrealistically small spread. Overall, the DPQPE had higher correlations, smaller RMS and mean absolute errors (MAE), and higher correlation coefficients relative to the gauge reports than did the PPS (Fig. 8). The error standard deviation (yellow bars in Fig. 8) is smaller for DPQPE, indicating that the errors fall within a smaller range than did those of the PPS. Applying a 1-tailed paired t-test to the mean absolute errors (0.09 vs. 0.10) shows that there is only a very small chance of < 0.01% that the difference of 0.01 inch is due solely to chance.

To evaluate algorithm performance differences in the more critical heavy precipitation cases, these comparisons were repeated within the set of 700 pairs in which at least one of the 1-h gauge reports or radar estimates was ≥ 0.5 inch (12.5mm). Though the radar estimates were still biased low relative to the gauge amounts (Fig. 9), the radar QPE standard deviations were closer to the gauge value than they were in the total sample. In terms of error and correlation, the DPQPE showed a proportionally larger improvement over the PPS than in the general sample (Fig. 10). The RMSE and MAE were both approximately 0.1 inch smaller for the DPQPE than for the PPS.

These errors indicate that while DPQPE shows improvement over the PPS, neither performs with high absolute accuracy for cases ≥ 0.5 inch. The average absolute fractional error (absolute error divided by gauge amount) is 0.5 for DPQPE and 0.65 for PPS (Fig. 11 orange bars). The fraction of cases with ≥ 25% fractional error was 0.69 and 0.79 for DPQPE and PPS, respectively, as shown by the Fig. 11 green bars. This latter result indicates that the DPQPE produced 13% fewer large errors.

The differences in DPQPE and PPS performance relatively close to the radar are of operational importance, since in many areas of the conterminous United States (CONUS) network no geographic point is more than about 160 km from the nearest WSR-88D unit, and mosaicking applications in the Advanced Weather Interactive Processing System (AWIPS) can be used to extract data from whichever is the nearest radar to any given point. Therefore, the error and correlation analyses in which the rain gauge and either the DPQPE or PPS algorithms had nonzero precipitation were repeated for all 1-h pairs within 150 km of the radar unit; this data sample had NNNN estimates. Both DPQPE and PPS performance were better within 150 km of the radar unit than in the 230 km umbrella, in terms of correlation coefficient (Fig. 12). Only minor differences within the 150- and 230-km umbrellas were apparent for the other statistics, as indicated by comparison between Figs. 8 and 12. However DPQPE performance was still measurably better than PPS in the 150-km range umbrella.

It is possible that part of the apparent improvement realized through the use of dual-polarization could be attributed to our verification practice of applying only one Z-R relationship in the PPS throughout all the storm events. In operations, field personnel have the option of choosing among multiple Z-R relationships depending on the meteorological situation. To test the impact
of dual-polarization input in the absence of a non-unity bias, we repeated our analyses of the total dataset but after estimating and applying mean-field bias corrections to both the dual-polarization and PPS estimates. The bias factors were estimated from all nonzero G/R pairs within each event, and was specific to that event. This adjustment is the type that could be made for long-term retrospective precipitation studies, when gauge data could be collected and quality-controlled, rather than that which could be done in real time.

With this adjustment, we found appreciable improvement in the both the DPQPE and PPS estimates, as shown by comparison between Figs. 8 and 13. After bias correction, correlations were higher and mean absolute errors were lower. However the improvement in PPS was more dramatic, such that the performance of the two algorithm suites became nearly indistinguishable, with the minor exception that DPQPE correlation to gauges was still slightly better than that of PPS. It should be noted, however, that this was a more comprehensive adjustment than could be carried out in real time, particularly since it involved one of the most dense gauge networks available over any WSR 88D umbrella in the entire CONUS. Further investigation of the possibilities for rain gauge correction of the dual-pol QPE will be explored in the next section.

While this study has been focused on verification of precipitation amount, future evaluation will include tests of precipitation/nonprecipitation discrimination. A common feature in PPS estimates during the spring-summer-autumn seasons is a circular region of anomalous, light precipitation centered on the radar unit, particularly at night. These returns are from biota, particularly migrating birds, insects, and bats – aerial, moving targets that are not filtered by PPS preprocessors. It appears that the hydrometeor classifier algorithm is working effectively to reduce this effect, as shown in Fig. 14. The reflectivity field (Fig. 14a) shows both precipitation and, close to the radar, biota echoes. The biota is identified by the hydrometeor classifier (Fig. 14b) and is removed from the DPQPE precipitation rate (Fig. 14c). We anticipate that this enhanced quality control will facilitate downstream applications in AWIPS, in which considerable effort must sometimes be expended by field staff to manually edit data from PPS precipitation grids.
Figure 1. Geographic distribution of reporting sites within the Oklahoma Climate Survey Mesonet, the Oklahoma City Micronet, and the USDA Agricultural Research Service Micronets.
Figure 2. Gauge/radar bias correction factor over the total event for ten storms, for DPQPE and PPS algorithms. Beginning dates as indicated. Values > 1.0 indicate underestimation, values < 1.0 indicate overestimation. Vertical red line separates 2010 and 2011 events. All cases were from the KOUN unit, except that Of 8 March 2011, which was from the KVNX unit.

Figure 3. Linear correlation coefficient between radar and gauge reports for the storm total precipitation of the events shown in Fig. 2.
Figure 4. As in Fig. 3, except root mean-squared error (inches).

Figure 5. As in Fig. 4, except fractional root mean-squared error (RMSE divided by the mean gauge-based precipitation).
Figure 6. As in Fig. 3, except linear correlation among all hourly gauge radar pairs within each storm event.
Figure 7. Mean (cyan bars) and standard deviation (green bars) for 1-h precipitation from gauges, DPQPE, and PPS.

Figure 8. Error statistics including mean absolute error (MAE) for 1-h values from DPQPE and PPS.
Figure 9. As in Fig. 7, except only gauge/radar pairs with \( \geq 0.5 \) inch precipitation indicated by gauge or radar.

Figure 10. As in Fig. 8, except only gauge/radar pairs with \( \geq 0.5 \) inch precipitation indicated by gauge or radar.
Figure 11. Average fractional absolute error and fraction of gauge/radar pairs with ≥ 25% absolute error, for all cases with precipitation ≥ 0.5 inch.
Figure 12. As in Fig. 8, except statistics from gauge/radar pairs within 150km range of the KOUN radar unit.

Figure 13. As in Fig. 8, except after correction of event mean-field bias. Note that the right-hand scale is different from that in Fig. 8.
Figure 14. Effects of hydrometeor classification algorithm on filtering “night bloom" from echoes at bottom of reflectivity image (a), which is identified as biota and coded gray in (b), and eliminated from the precipitation rate product (c). Images are from 1021 UTC, 19 May 2010, from KOUN unit.
3. Task 1.1: Evaluation Of Real-Time Bias Correction Impacts On Dual-Polarization Precipitation Estimates

a. Experimental Design

As noted above, there are significant time-dependent biases in both dual-polarization and single-polarization rainfall estimates (Fig. 2); moreover the single- and dual-polarization QPE biases are strongly correlated to one-another in time. To test the possibilities for real-time gauge-bias adjustment of the DPQPE, we applied the available data to estimate, for each gauge/radar pair, time-varying bias adjustment factors. These were done in three ways: from the entire radar umbrella (mean field); from gauges at similar ranges; and from nearby gauges. A cross-validation approach was employed in which only data from other sites, at the same or earlier times, were used in estimating the bias correction factors to be applied to the given verification gauge.

Multiple forms of bias correction were tested. The simplest, long-term bias correction (designated LTB) is the sum of all nonzero gauge reports divided by the sum of all nonzero radar reports within 60 km of the verification site, over the entire period of record. Again, the LTB for each site was estimated only with data from other sites. The LTB is analogous to a multi-month or multi-year bias adjustment specific to a part of a radar umbrella. A time-dependent, mean-field bias (MFB) was estimated in a similar manner at sites throughout the umbrella, but only using reports available from the current time backward through a limited time window, in a manner analogous to using reports in real time. A time- and range-dependent bias (RDB) was estimated for a limited time window, but only from data at sites within an annular region 120 km wide concentric on the verification point. Finally, a time-dependent local bias correction (LB) was estimated only from data at other gauge sites within a 60 km radius of the verification point.

The MFB and LB corrections are analogous to fields available in the Multisensor Precipitation Estimator (MPE). We did not use this operational version due to the extensive number of reruns that would be necessary to carry out a cross validation.

Our analysis includes a time dependency factor for data entering the MFB, RDB and LB corrections. All gauge radar pairs within two hours of the current time were given a statistical weight of unity. If at least a threshold number of nonzero pairs could be located within this time window, and within the applicable space window, the bias correction was determined from these pairs. This threshold minimum was chosen as ten pairs, consistent with the current, operational default in MPE.

If the minimum of ten pairs was not available within two hours, data from earlier pairs were added to the gauge and radar sums with a weight inversely proportional to the time difference, such that the statistical weight decreased to 0.1 after a 24-h time lag. All pairs more than 24-h old were weighted as 0.1. In practice, over 90% of the mean field bias values could be calculated with data < 3h old when the full network was used; this percentage dropped to approximately 10% for estimating LB values from the thinnest network.
The bias estimation experimental procedure can be summarized as follows. All available gauge-radar pairs were assembled in increasing time order. For each site, the LTB was estimated from data at other nearby sites over the entire period of record (May 2010-February 2011). Then for each individual gauge-radar pair, MFB, RDB and LB were estimated from data from other sites, at the current time backwards as far as necessary to collect at least ten time-weighted nonzero gauge-radar pairs. The verifying gauge report, the original DPQPE radar estimate, and the four bias-corrected estimates were then added to an evaluation dataset for statistical analyses.

Because the original verification dataset included observations from four densely-instrumented micronetworks, which are not commonly available in operations, we removed all data originating at those sites, retaining only the 91 sites of the Oklahoma Climate Survey’s mesonetwork. The experimental sample was thus reduced to 2878 cases. This mesonetwork is still more dense than the operational networks available in many critical areas. We therefore repeated the cross-validation experiments with several degrees of artificial thinning. This was accomplished by skipping over a specified number of available gauge-radar pairs, in each iteration, when searching the time-ordered list for reports to add to the bias estimate. Therefore, a random set of gauge sites was used in the thinned networks, rather than a fixed set.

Only those verifying pairs for which all three time-dependent biases could be calculated were employed in calculating our statistics. This resulted in some of the earlier cases being dropped from the thinnest network verifications. The verifying samples all contained between 1100 and 2700 cases.

b. Results

The effects of different bias corrections on RMS error are shown in Fig. 15. The families of error bars are arranged left to right in order of decreasing network density. The notations (4), (2), (1.5), and (1.1) refer to the average number of available gauge sites within 60 km of the verifying site under the different thinning criteria. Because the statistics for each network configuration were computed only from cases in which all bias corrections could be made, the samples are not matched and the RMSE for the original DPQPE varies among the verification groups.

The LTB correction (dark magenta bars in Fig. 15) always yielded some small reduction in RMSE compared to the original, non-bias-corrected version, but generally less than 0.01 inch. For the full- and half-network configurations, as shown in the two left-side families, mean-field, range-dependent, and local bias corrections yielded RMSE improvements of up to 0.02 inch. The 1/4th and 1/8th network configurations yielded only very small improvements < 0.01 inch for most of the bias assumptions. Because the MFB correction incorporates no geographic dependency, it sometimes yields little or no improvement or degradation in the error statistics. Generally smaller RMS errors, but otherwise similar results, were found for cases with verifying gauges within 150 km of the radar (Fig. 16).

The bias corrections might have a more appreciable impact in reducing errors in heavy precipitation situations. Considering only cases with gauge or radar precipitation > 0.5 inch, we determined the fraction of estimates that were more than 25% in error. Results for the 230-km
and 150-km radar umbrellas are shown in Figs. 17-18. We found that the time-dependent corrections could reduce the percentage of 25% amount errors by up to 15% (e.g., from 0.7 to 0.6 of the cases). These results held for even the thinner networks.

While the current MPE software is not configured for bias correction of DPQPE products, it appears that the basic principle is sound and should be considered for operational implementation.
Figure 15. RMS errors for original DPQPE estimate, and after long-term, mean-field, range-dependent, and local bias adjustments. Notations Xga refer to the average number of rain gauge sites within 60 km of the verification point, for the full OCS network (4ga), and after different degrees of artificial thinning of the network.

Figure 16. As in Fig. 14, except for only gauge verification points within 150 km of the KOUN unit.
Figure 17. Fraction of cases in which precipitation is $\geq 0.5$ inch and the radar estimate absolute error is $\geq 25\%$ of the gauge value.

Figure 18. As in Fig. 16, except for only gauge verification sites within 150 km of the KOUN radar unit.
4. Evaluation of Non-uniform Beam Filling Correction Algorithm

a. Background

In early testing of the initial-release version of the WSR-88D dual-polar software package at the WSR-88D test-radar in Norman, OK (KOUN), Attenuation/Non-uniform Beam Filling (NBF) was deemed to be problematic, with potentially serious impacts on numerous, derived fields including Hydrometeor Classification and Precipitation Rate, and consequently, on Quantitative Precipitation Estimates, or QPEs. The attenuation and NBF phenomena cause vertical/horizontal cross correlations to be unrealistically low for precipitation regions, which can result in heavy precipitation being unclassifiable for, usually, brief time intervals. It is sometimes not apparent whether attenuation phenomena, or a nonuniform distribution of multiple hydrometeor types within single sampling volume (NBF), are behind such occurrences; the two effects probably often occur together and henceforth we generally refer to them collectively as NBF.

A first-revision version of the code was then developed, at NSSL, containing logic aimed at addressing these deficiencies. Adaptable parameters in this version were set so as to be rather conservative in identifying suspect radials, with the intention of catching at least the most problematic ones without, perhaps, causing inadvertent problems.

The original vs. revised versions of the dual pol code were then compared on ten cases during 2010 in which negative impacts of NBF were observed. The comparison was done both quantitatively, on hourly and storm-total statistics compared against rain gauges, and qualitatively, via examination of base products and analogous, derived products.

Independently, an effort was undertaken at the ROC to subjectively identify radials showing evidence of NBF, using criteria similar to that built into the initial-fix code version. The results of running the ten cases after the fix (i.e. which radials were identified and corrected) were then compared against those identified by the subjective effort at the ROC, as well.

b. Examples from 19 May 2010 event

The evaluation process is best illustrated by the most obvious instance of NBF effects, on 19 May 2010. As shown in Fig. 19, which illustrates phenomena in the early phase of the event, a line of intense echoes was oriented along the radar radials to the northwest of the KOUN site. Some unrealistically low reflectivity values appear in the shadow of this line (Fig. 19a), along with very low correlation coefficients (Fig. 19b).

The considerable impact of these effects is shown in Fig. 20a,c. The sector of the storm with low correlations was deemed unclassifiable (“unknown” or UNK) by the hydrometeor classification algorithm, and precipitation rates were therefore set to zero by the DPQPE. In practice, this would result in unrealistic precipitation rate-time series over the affected area.

Application of the NBF correction resulted in retrieval of precipitation in that sector, now classified as “heavy rain/hail” and featuring some precipitation rates as high as 3.25 in h⁻¹ (Fig. 20b,d).
Visual evaluation of these digital radar data, based on some of the same criteria as the NBF-mitigation logic, identified 30 radials as being impacted at this time, corresponding to azimuths 307-309, 312-314, 318-338, and 351-003. The wedge of 4-5 radials behind the bow-shaped region of very heavy echoes to the NNW appears to be much more severely impacted than the rest. We found that the revised preprocessor program picked out only radials 336-340 for correction. These represent only 17.5% of those subjectively identified but 100% of those severely impacted.

A set of images, indicative of middle phase of this storm event, particularly for about an hour during 10:30-11:30 UTC, is shown in Fig. 21. The NBF correction seems to have improved the storm representation overall in terms hydrometeor classification and precipitation rates, though apparent errors were introduced in some radial. In particular, a region of echoes with non-precipitation classifications due north of the radar and behind the most intense precipitation was reclassified correctly. However, two radials to the north and northwest that were correctly classified as precipitation before the correction were changed to “unknown” category (Fig. 21a,b). Closer investigation revealed this to be a consequence of dissimilar values of adaptable parameters for Correlation Coefficient (CC) used in two portions of the code – the NBF correction and DPQPE, as well as a “cut-off” threshold used for ‘completeness’ in the building of the hybrid scan precipitation rate product. The NBF correction used 0.7 for its CC max threshold in identifying NBF-impacted radials while DPQPE used 0.85 for its CC min threshold for excluding non-precipitating echoes. This situation leads to a window of bins that are neither NBF-mitigated nor used in DPQPE; if such bins are still present when the “cut-off” threshold (99.7%) is reached at the end of an elevation scan, these ‘unknowns’ will be incorporated into the hybrid scan and precipitation rate products. Experimentation with adaptable parameters could yield improvement in these unusual circumstances.

The potential impact of these corrections on accumulations is sometimes considerable, as illustrated in Fig. 22 for two 1-h periods later in this event. The accumulations are increased from under 0.5 inch to well over 1 inch in the sector northeast of the radar (Fig. 22a,b); one hour later the accumulations were enhanced to a similar degree in the area farther east. An evaluation of the storm total precipitation for this 11-h event by comparison with gauge reports showed substantial improvements in MFB from 1.29 to 1.18, and in RMS error from 0.43 to 0.39 inch.

c. Results from other events

While some of the other ten events studied here were affected at least moderately by the NBF correction, most had only minor impacts. Besides the 19 May case, the 10 May, 25 May and 7 June events had some obvious impacts, though usually short-lived. Visual examination sometimes showed that areas of unknown hydroclass and anomalously low precipitation rates received defined hydroclasses, consistent with their neighboring bins, and higher precipitation estimates, after the correction. However, for these cases, the effect was fleeting and usually not picked up by the rain gauge network.
d. Summary of NBF events

Of the ten cases investigated, in only the May 19 event did the initial logic fix make a significant difference (improvement) statistically. That case was characterized by a long-lasting period during which a significant area was impacted by Attenuation/NBF. This improvement was achieved despite the fact that the logic-fix version flagged and corrected only 19% of the (1255) radials that were subjectively identified (over a 7-hour period) as being NBF-impacted. It should be noted that, as at the time (volume scan) featured in Fig 20 and described above, those radials that were most significantly impacted tended to be those most likely to be corrected, throughout the event.

Please note that this validation activity was not an attempt to rigorously verify the specific criteria by which NBF-impacted radials were identified, either by the code (logic) or the subjective identification activity. However, it often appeared that radials with a significant run of sample bins with correlation coefficients <.7 were corrected, while those with correlations >.8 often were not.

In a few instances, a radial or two were seen to be negatively impacted by the fix, including almost continuously during about an hour period of the May 19 case. However, in these instances, the NBF-affected area improved by the fix far outweighed that degraded by it. In several of the other events, similar results were seen as in May 19 with regard to the more seriously (visually) impacted radials being corrected, but not the less seriously impacted ones. However, in these cases, the NBF phenomenon was not as long-lasting nor as extensive, or perhaps was not picked up by the gauge network; hence, little or no difference was seen in the verification statistics for precipitation-accumulation (see Table 1).

Overall, the NBF correction logic is assessed as having been rather effective in mitigating the worst impacts of Attenuation/NBF observed in the initial-release DP software version. However, repetition of the experiment after adjusting adaptation parameters is recommended. For example, the minimum CC might be changed from 0.7 to 0.8; minimum reflectivity (Zmin) from 30 to 25 dBZ; %Filled from 99.7 to 99.9, to assess whether more radials can be corrected while “doing no harm”

5. General Summary

The major results of the past year’s work include validation of the DPQPE approach and verification of its superiority to the currently-operational PPS; verification of the effectiveness of an NBF correction in the preprocessor package for hydrometeor classification and precipitation estimation; and a demonstration of the possibility for operationally significant improvements to DPQPE through real-time gauge/radar bias correction.

Current plans are for OHD staff to carry on evaluations to verify the DPQPE algorithm output and identify any operational problems during the course of the beta field test, to be carried out later in 2011. A plan for verifying the superiority of DPQPE to the operational PPS through assessments at operational sites has been put forward and is now under discussion.
Acknowledgements

The dual-polarization quality evaluation team includes staff from ROC Applications Branch, ROC Warning Decision and Training Branch, OST, and NSSL. We gratefully acknowledge their support and assistance in carrying out these evaluations.

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Figure 19. Reflectivity (a) and correlation coefficient (b) at 0.5° antenna elevation KOUN unit, 1021 UTC, 19 May 2010. NBF and attenuation effects are suggested by the sectors with low reflectivity and correlation coefficient < 0.7 in the upper left of these images.
Figure 20. Hydrometeor classification before (a) and after (b) NBF correction; DPQPE precipitation rate before (c) and after (d) NBF correction. Products are from the 0.5° antenna elevation, KOUN, 1021 UTC, 19 May 2010.
Figure 21. Hydrometeor classification before (a) and after (b) NBF correction; DPQPE precipitation rate before (c) and after (d) NBF correction. Products are from the 0.5° antenna elevation, KOUN, 1118 UTC, 19 May 2010.
Figure 22. One-hour precipitation accumulation products before (a,c) and after (b,d) NBF correction; accumulations ending at 1200 UTC (a,b) and 1256 UTC (c,d) 19 May 2010.
Table 1. Summary of results of tests of NBF corrections. Verification statistics are based on 1-h rain gauge reports.

<table>
<thead>
<tr>
<th>Case</th>
<th>Begin – End (# hours)</th>
<th># G-R pairs</th>
<th># diff &gt; = 0.01”</th>
<th># diff &gt; = 0.05”</th>
<th>MFB before</th>
<th>MFB after</th>
<th>RMSE before</th>
<th>RMSE after</th>
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<td>2010051011</td>
<td>23:04 - 01:27(2+)</td>
<td>31</td>
<td>1</td>
<td>1</td>
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<td>0.84</td>
<td>0.21</td>
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<td>20100519</td>
<td>02:09 - 12:57(11)</td>
<td>48</td>
<td>13</td>
<td>10</td>
<td>1.29</td>
<td>1.18</td>
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<td>06:04 - 11:57(6)</td>
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<td>1.04</td>
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<td>06:45 - 11:00(5+)</td>
<td>18</td>
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<td>09:11 - 14:55(6)</td>
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<td>11:31 - 17:58(6+)</td>
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<td>00:02 - 01:24(1+)</td>
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<td>09:02 - 11:56(3)</td>
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<td>00:04 - 22:00(22)</td>
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<td>07:44 - 10:58(3+)</td>
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<td>22</td>
<td>12</td>
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