P2.11 A MULTI-SITE EVALUATION OF THE RANGE CORRECTION AND CONVECTIVE-STRATIFORM SEPARATION ALGORITHMS FOR IMPROVING WSR-88D RAINFALL ESTIMATES

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1. INTRODUCTION

The Range Correction Algorithm (RCA, Seo et al. 2000), which has been developed by the Office of Hydrologic Development (OHD), National Weather Service (NWS), National Oceanic and Atmospheric Administration (NOAA), functions to reduce range-dependent biases in radar precipitation estimates due to nonuniform vertical profiles of reflectivity (VPR). It improves estimates of stratiform precipitation by approximating the mean VPR over the entire radar umbrella, then using the mean VPR to calculate and apply range-dependent multiplicative correction factors to radar reflectivity and/or Z-R precipitation estimates. RCA reduces bright band contamination at near-to-mid ranges from the radar, and enhances rainfall estimates at farther ranges, where the radar beam typically intercepts ice particles above the melting layer. To deal with situations of embedded convection, a companion algorithm, the Convective-Stratiform Separation Algorithm (CSSA, Seo et al. 2002, Ding et al. 2003), has been implemented in conjunction with RCA. If CSSA identifies those precipitation areas that are convective in nature; neither such areas contribute to the model of the stratiform VPR, nor is range correction applied there.

During February-May 2003, an internal evaluation of RCA was conducted in OHD using real-time data from single radar site KLWX (Sterling, VA) (Ding et al. 2004). To further extend this study, the OHD and several NWS field offices conducted a field evaluation of the RCA and CSSA during the period of March-May 2004, using real-time data from 6 WSR-88D sites: KRTX (Portland OR), KEAX (Pleasant Hill MO), KMPX (Minneapolis MN), KTLX (Twin Lakes OK), KPBZ (Pittsburgh PA), and KRLX (Charleston WV). Real-time data from KLWX were also collected for analysis in OHD. The purpose of the field evaluation was to obtain feedback from forecasters and hydrologists on the utility of these corrections to basic radar estimates, and to obtain a geographically diverse set of precipitation estimates for objective verification.

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The radar precipitation estimates were derived from Open Radar Product Generation (ORPG) Build 5 Digital Precipitation Array (DPA) products, generated at NWS headquarters from base reflectivity data collected in real time from the Advanced Weather Interactive Processing System (AWIPS) Local Data Monitor (LDM). One set (referred to as DPA after the operational designation) had no range correction, another set (DPR) had range correction applied, based on the RCA/CSSA package. The DPR products were also given a mean-field bias correction based on 1-h rain gauge reports from the operational Standard Hydrometeorological Exchange Format (SHEF) feed transmitted by the NWS.

During the field evaluation, forecasters at the field offices were given access to a web page featuring rainfall accumulations with and without range correction. Their evaluations of the performance of RCA and CSSA over discrete precipitation events were collected through standard questionnaires. Reception at field sites was positive in a clear majority of cases. Each survey included impressions of RCA performance during a single event at the site. Of 17 surveys returned, 15 indicated that the RCA/CSSA performed as expected (reduced estimates in brightband zones, increased estimates beyond the brightband, little effect if no brightband was evident). Also, 15 of the 17 indicated that there would have been operational benefit from RCA/CSSA in the particular case reported on.

The organization of this paper is as follows. In section 2, precipitation characteristics during the experiment are analyzed only using radar data. In section 3, the results of objective evaluation of RCA and CSSA through our post-analysis are shown. Section 4 provides conclusions.

2. PRECIPITATION CHARACTERISTICS DURING THE EXPERIMENT

The effects of bright-band overestimation and range degradation on precipitation estimates, and the character of range correction adjustments, are illustrated for 6 evaluation sites in Figs. 1-6. In each figure, the plan-position indicator display at the upper left shows total precipitation for all available hours during 3 calendar months based on the uncorrected

DPA product. The display at upper right shows the total for all range-corrected (DPR) estimates, and that at lower left the difference field between the two. At the lower right, an azimuthal average of both original and range-corrected estimates is shown as a function of range. Some range-dependent artifacts are apparent in the total DPA and DPR fields near most of the radar sites, due to the use of different antenna elevation angles in constructing the Digital Hybrid Scan reflectivity field that provided the rainrate estimates.

The fields for Pittsburgh, PA (KPBZ, Fig. 1) show characteristics most typical of cool-season precipitation estimates and range-correction effects, with clearly-visible zones of overestimation (roughly 50-170 km range) and underestimation (beyond 170 km). The most obvious effect of range correction is the reduction in precipitation estimates between 70 and 170 km, with some increase in the estimates beyond 180 km.

Range effects and range correction effects are similarly evident in the Charleston, WV umbrella (KRLX, figure not shown), though this umbrella features a zone of underestimation to the southeast caused by partial beam blockage due to terrain.

The field for KRTX (Fig. 2) is atypical in that this site experiences significant beam overshooting during much of the winter and spring, and thus little precipitation is detected beyond about 120 km from the radar. Under these conditions, the detected VPR is nearly uniform with height out to fairly long ranges, and range correction has little effect. Here, range correction results mainly in a small increase in the estimates at most ranges.

There was little precipitation in the Minneapolis, MN (KMPX, Fig. 3) umbrella until late in the study period; rain totals were rather small and there was little evidence of bright-band contamination. The rain total fields were also asymmetric, with much larger total accumulations over the southern portion than the northern. However, range correction still had the expected effect of decreasing some mid-range estimates to the west of the site, and increasing them at longer ranges.

Another site where precipitation was dominated by a rather small number of events late in the period was Oklahoma City, OK (KTLX, Fig. 4). However, these events were primarily convective in nature, and peak 1-h rainfall totals were significantly larger than at most other sites. While range correction had the expected effect (lowering mid-range estimates and raising those at longer ranges) there were only a modest changes in rainfall estimates relative to the total amounts.

The distribution of total precipitation over the Kansas City, MO umbrella (KEAX, Fig. 5) suggests some bright-band enhancement, though there is again some azimuthal asymmetry. Range corrections were larger in magnitude, relative to the total amounts, than for the other central U.S. sites at KMPX and KTLX.

Though the Sterling, VA umbrella (KLWX, Fig. 6) partially overlaps those of KPBZ and KRLX, its precipitation totals field shows less evidence of bright-band effects, and range correction produced only small changes in the original estimates.

3. OBJECTIVE EVALUATION OF RCA/CSSA

A post-analysis was designed to quantify the degree of improvement offered by RCA/CSSA. It was also used to separate the effects of range correction from those of mean-field bias adjustment, since both elements were combined in the field evaluation.

The range-corrected (DPR) estimates differed from those displayed in real time on the OHD web page in that a different, more statistically stable form of correction was applied in the post-analysis. In the real-time products, the adjustment factors calculated from the reflectivity profile at the end of the hour were applied to estimated rainfall during the entire hour. In this post-processing experiment, a different logic was employed, closer to that which would be used when range correction is fully integrated with the PPS. The range adjustment factors averaged over the entire hour were applied to the 1-h precipitation amount. This reduces the influence of random variations in any one vertical profile of reflectivity that may occur during the hour. Note that this post processing did not introduce any new information to the range correction process; it only utilized some information that was available but not used in the real-time experiment.

Both DPA and DPR estimates were collated with 1-h gauge reports from the operational network. Only cases in which the 1-h radar estimate and gauge value were both nonzero were included. Other than elimination of cases where the gauge report exceeded 2.5 inches, no attempt at quality control was made. No attempt was made to identify or remove reports of frozen precipitation, though some occurred in the KPBZ and KMPX umbrellas during the data collection period. The collation process yielded a total of 24,315 cases, with between 320 and 6,893 cases for each of the seven sites.

The DPR product generally improved on the DPA product, both in terms of statistical bias and arithmetic error. As shown in Table 1, the radar estimates featured a positive bias (overestimation) at all sites. This was particularly evident at the easternmost sites (KPBZ, KRLX, KLWX), where some effect from melting snow aloft was evident during much of the experimental period. Note that here we refer to bias as the ratio (radar estimate)/(gauge report), while in some OHD documents the inverse, or bias correction factor, is used.

Range correction led to consistent improvement in terms of bias and Mean Absolute Error (MAE), at individual sites and in the sample as a whole. Improvement in terms of Root Mean Square Error (RMSE) was not consistent, indicating the presence of some cases with larger errors in the range-corrected sample. At the KTLX site, range correction actually resulted in an increase in a positive bias (from 1.37 to 1.4). This site had consistently higher rain rates than the other sites, and many of its events featured widespread convection, conditions in which range correction typically has little effect. It should be recalled that this site contributed only 8% of the total sample, however.

The 1-h data were then aggregated into 3-h accumulations for all possible contiguous 3-h periods, and the statistics recomputed. Since many of the 1-h samples were not contiguous, only 5105 3-h cases could be collected. As shown in Table 2, improvement due to range correction was more consistent within this sample than in the sample of 1-h amounts, probably due to canceling out of some random errors. Except for the KTLX cases, both MAE and RMSE were now consistently lower for the range corrected sample.

While these statistics are encouraging, they show only that range correction is effective in the majority of cases, and improvement over the uncorrected estimates might be due mainly to routine correction of small errors. However, as shown in Table 3, the DPR sample also had fewer large 1-h errors, in excess of 0.25 inch (6.3% of DPR estimates vs. 9% of DPA estimates). Even within the KTLX sample, the occurrence of these rather large errors increased only slightly from the DPA to the DPR sample (15.8% for the DPA compared to 16.0% for the DPR). We also determined that cases in which the DPR significantly degraded the DPA were rare. We found that range correction increased an absolute error of ≤ 0.1 inch to ≥ 0.05 inch in no more than 3.5% of cases at any one site, and in only 2.7% of cases overall.

The post analysis included an investigation of the effects of a mean-field bias (MFB) correction (Seo et al. 1999) to the original and range-adjusted precipitation estimates. Because of predominating atmospheric conditions, in which an elevated melting layer apparently lead to overestimation of most of the radar umbrella, the MFB correction alone often had nearly the same effect as range correction.

However, this is not necessarily the case in colder situations, in which the umbrella features both bright-band overestimates and long-range underestimation due to snow. An analysis of KLWX data from the 2003 experiment (Ding et al. 2004) showed that under these conditions a combination of range correction and MFB correction function significantly better than does either correction alone. For the period February-March 2003, there were 1174 radar/gauge pairs, with a mean 24-h amount of 9.1 mm. The RMS error for 24-h rainfall estimates based on the uncorrected DPA was 7.1 mm, the error for MFB-corrected estimates was 6.2 mm, and the error for estimates with both MFB and range correction was 4.8 mm.

Thus it appears that in the most general sense, range correction and MFB correction should be applied together. We were encouraged by the finding that range correction alone substantially reduced the high bias present in the original estimates, without the use of coincident raingauge observations.

4. CONCLUSIONS

Overall, the incorporation of RCA/CSSA had a significant positive impact on the precipitation estimates, in terms of both statistical reliability (reduction of bias) and in reducing the magnitude of errors.

The greatest positive impact was evident at the three eastern sites, probably because they were most affected by stratiform rain under cool conditions. Near KPBZ and KRLX in particular, range correction alone had substantial positive impact on reducing an unrealistically high bias. Note that under even cooler conditions, such as late autumn and winter, we would expect to see some negative bias without range correction.

Analysis of results from KEAX and KMPX was hampered by frequent data dropouts. Moreover conditions were generally dry in the KMPX umbrella over much of the period. However, RCA/CSSA had a positive impact on their rainfall estimates.

The RCA had minimal but positive impact at the KRTX site, which is sited such that its beam often overshoots much stratiform precipitation. Consequently, there is only limited range effect to correct within that umbrella. Moreover, the study period was rather dry there.

For the KTLX cases, it appears that much of the precipitation was convective in nature, or more intense stratiform. A rather high cutoff for identifying precipitation as convective within the CSSA (80%) was in use throughout the study period, and it seems that this criterion should be lowered.

The study did highlight the potential need for modifications to the criteria used to apply the algorithm. First, the range adjustment factors should be applied only to rainrates during the current volume scan, or should be temporally averaged if applied to a 1-hour or longer accumulation. Second, range correction should be cancelled in situations with the brightband very close to the ground. In these instances, with melting snow at the bottom of the mean reflectivity profile, no meaningful estimate of liquid precipitation at the surface is possible. Third, some minimal areal precipitation coverage must be considered as a criterion for application of range correction, since it is not possible to derive a realistic reflectivity profile when precipitation is only spotty and distant from the radar. Finally, the convective probability used as a yes/no cutoff for convection should be lowered from 80%, thus rejecting more suspect data as input to the reflectivity profile, and correcting a smaller fraction of the overall area when some convection is evident.

Operational implementation of the RCA and CSSA algorithms within the Radar Product Generator has been deferred in favor of higher-priority upgrades. However, we are investigating its possible implementation within AWIPS, as part of the Multisensor Precipitation Estimator package.

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Table 1. Verification for 1-hour precipitation amounts, March-May 2004. DPA is for operational Digital Precipitation Array rainfall estimates, DPR is for range-adjusted rainfall estimates. This analysis includes all available instances in which radar estimates and collocated gauge estimates were both nonzero. No attempt was made to remove cases with snow at the surface. Note that no gauge information was used in calculating DPR. Rain gauge observations from operational SHEF feed. Bias is (radar value)/(gauge value). MAE is mean absolute error. RMSE is root mean square error. Amounts are in inches.

Site	**Number of cases**	**Mean gauge (inch)**	**DPA bias**	**DPR bias**	**DPA MAE (inch)**	**DPR MAE (inch)**	**DPA RMSE (inch)**	**DPR RMSE (inch)**
KRTX	719	0.08	1.60	1.36	0.082	0.063	0.119	0.105
KMPX	320	0.13	1.43	1.24	0.108	0.090	0.153	0.167
KTLX	1948	0.17	1.37	1.41	0.138	0.142	0.192	0.272
KEAX	2045	0.13	1.56	1.23	0.111	0.085	0.158	0.162
KRLX	6893	0.11	1.68	1.20	0.110	0.079	0.150	0.136
KPBZ	9406	0.11	1.63	1.18	0.100	0.072	0.137	0.131
KLWX	2984	0.12	1.24	0.96	0.095	0.078	0.140	0.143
ALL	**24315**	**0.12**	**1.55**	**1.19**	**0.106**	**0.081**	**0.148**	**0.152**

Table 2. As in Table 1, except verification for 3-hour precipitation amounts, March-May 2004. Analysis includes all cases where there was nonzero radar and gauge precipitation for 3 contiguous hours. Some 3-h periods overlap. Site KMPX had < 10 such observation sequences and is not included.

Site	**Number of cases**	**Mean gauge (inch)**	**DPA bias**	**DPR bias**	**DPA MAE (inch)**	**DPR MAE (inch)**	**DPA RMSE (inch)**	**DPR RMSE (inch)**
KRTX	105	0.27	1.83	1.53	0.296	0.259	0.36	0.34
KMPX	--------	--------	--------	--------	--------	--------	--------	--------
KTLX	331	0.67	1.20	1.15	0.338	0.338	0.41	0.66
KEAX	403	0.49	1.43	0.99	0.223	0.223	0.34	0.31
KRLX	1525	0.35	1.75	1.12	0.196	0.196	0.40	0.28
KPBZ	2102	0.35	1.73	1.16	0.188	0.188	0.38	0.32
KLWX	628	0.37	1.38	0.96	0.173	0.173	0.34	0.33
ALL	**5105**	**0.36**	**1.61**	**1.11**	**0.203**	**0.203**	**0.38**	**0.34**

Table 3. Relative frequency of significant absolute errors in 1-h estimates

Site	**Cases with DPA errors ≥ 0.25 inch**	**Cases with DPR errors ≥ 0.25 inch**	**Cases with DPA error<0.05 inch and DPR error > 0.1 inch**
KRTX	4.0%	2.1%	0.5%
KMPX	10.3%	8.1%	2.8%
KTLX	15.8%	16.0%	3.0%
KEAX	8.8%	6.8%	3.5%
KRLX	9.9%	5.8%	2.5%
KPBZ	7.9%	4.8%	2.5%
KLWX	6.6%	5.7%	3.0%
ALL	**9.0%**	**6.3%**	**2.7%**

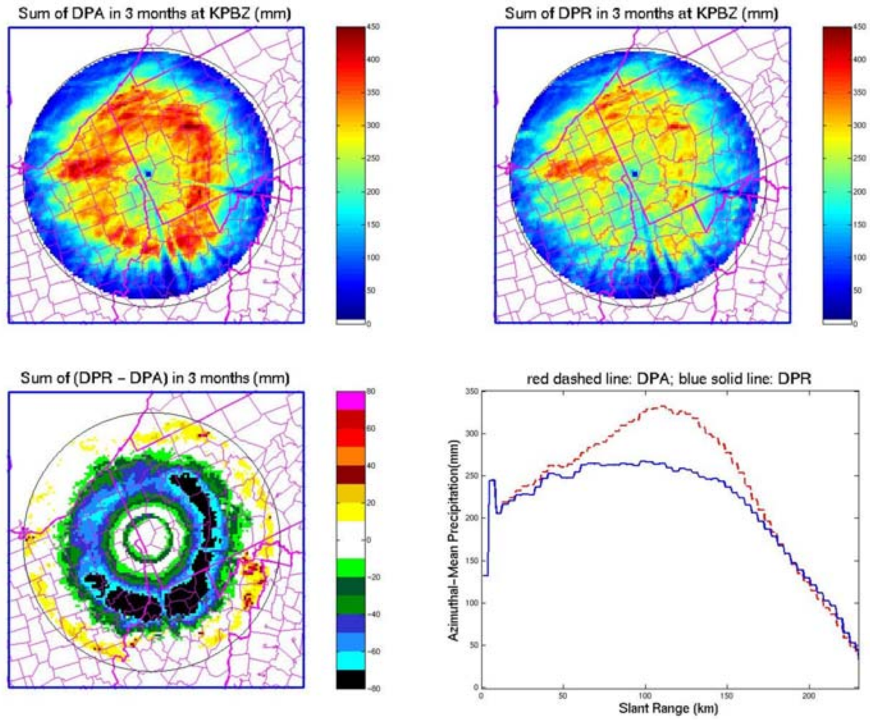

Figure 1. Sum of DPA estimates (top-left), DPR estimates (top right), difference (DPR - DPA) (bottom left), and azimuthally-averaged precipitation vs. slant range (bottom right) in KPBZ umbrella over 3 months (March - May, 2004). Only those cases with radar observations were included. All amounts are in mm.

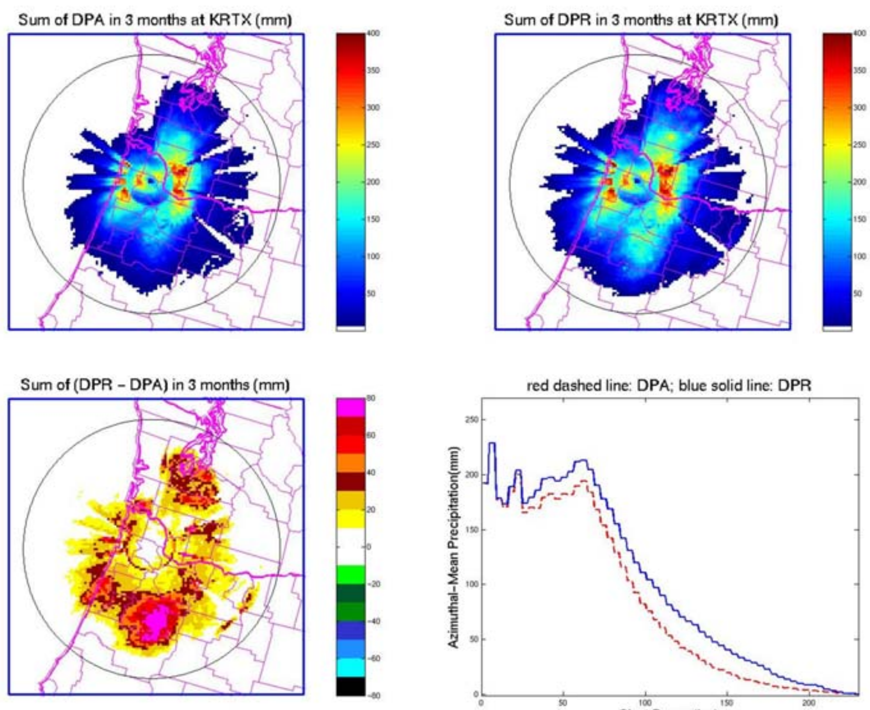

Figure 2. As in Fig. 1, but for KRTX umbrella.

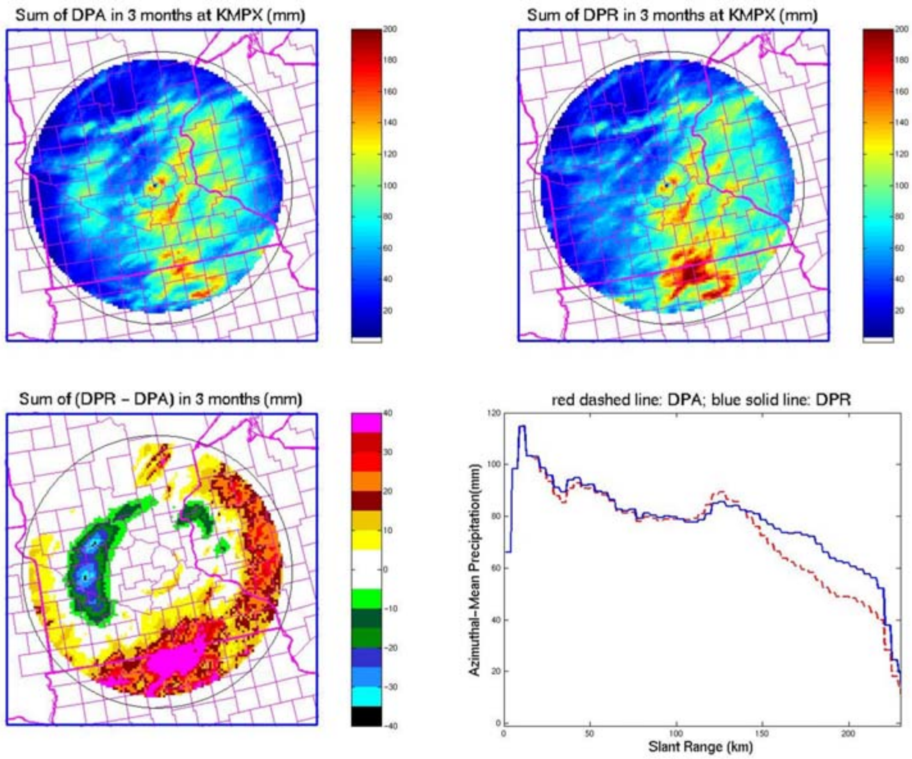

Figure 3. As in Fig. 1, but for KMPX umbrella.

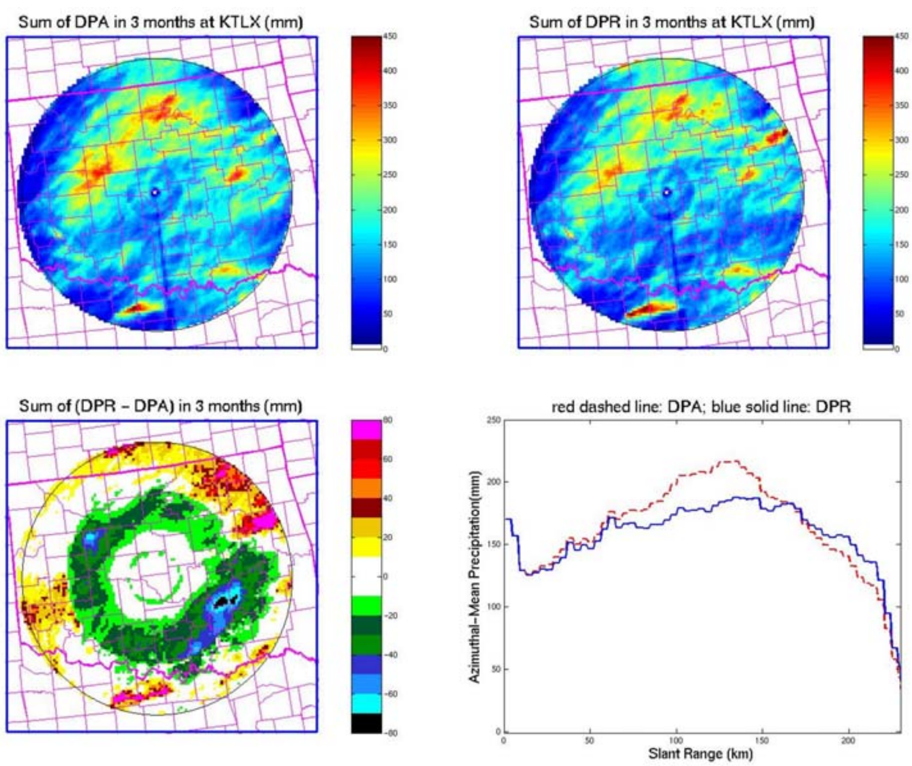

Figure 4. As in Fig. 1, but for KTLX umbrella.

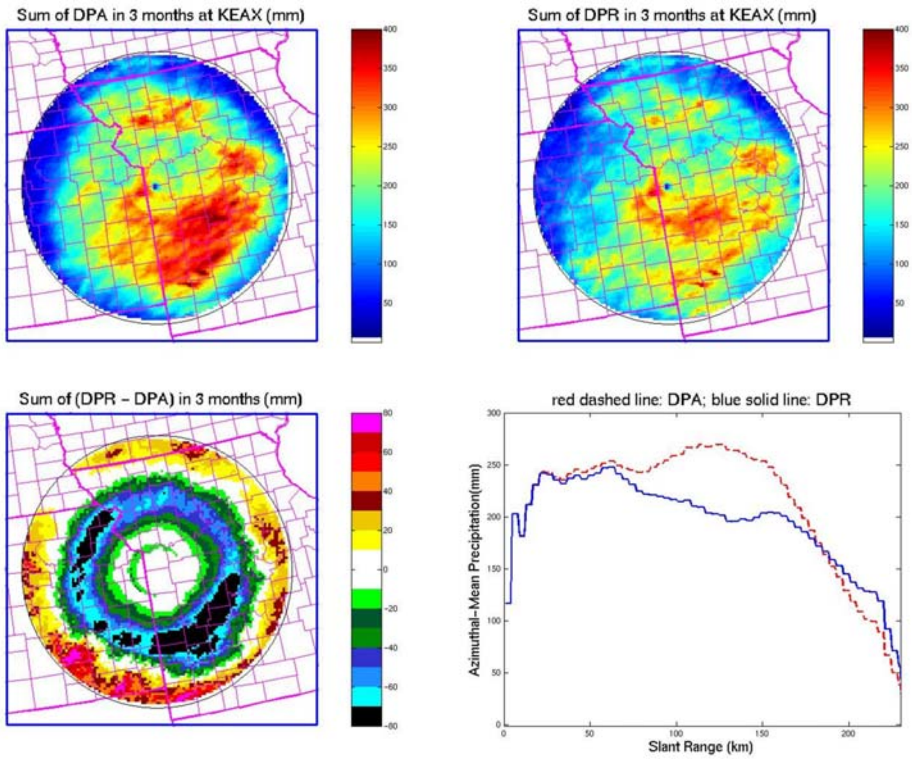

Figure 5. As in Fig. 1, but for KEAX umbrella.

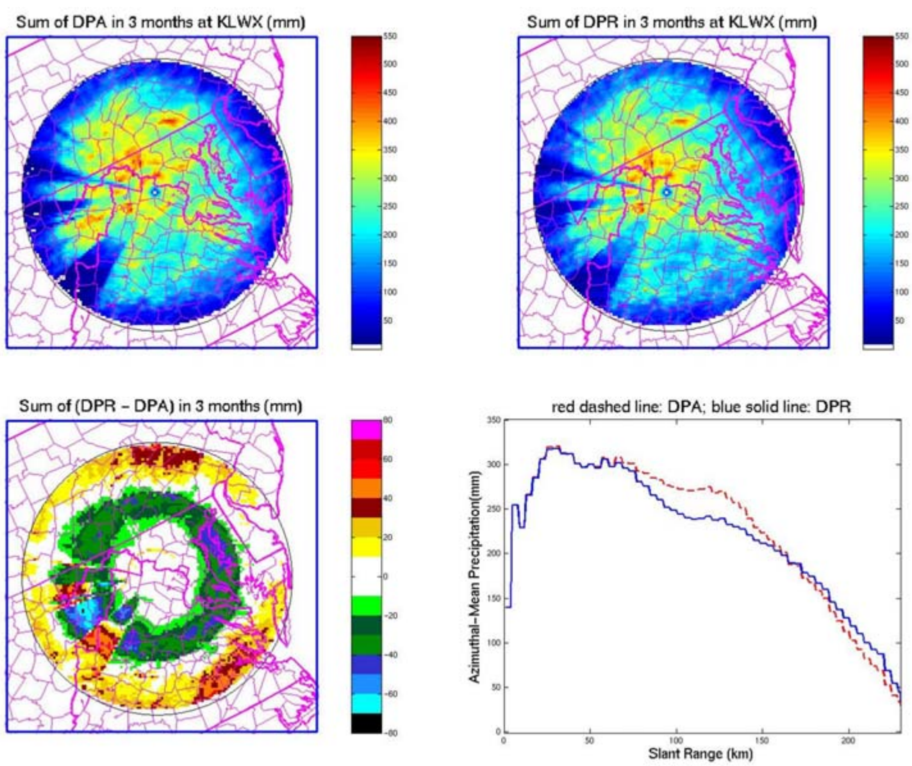

Figure 6. As in Fig. 1, but for KLWX umbrella.