Chapter 1.
Verification Statistics for 1-Hour and 3-Hour Radar Precipitation Estimates With and Without Range Correction

1. Introduction

A field evaluation and post-analysis of the Range-Correction Algorithm (RCA) and Convective Stratiform Separation Algorithm (CSSA) was conducted by the Office of Hydrologic Development (OHD) during the period March-May 2004. 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.

The RCA is documented in Seo et al. (2000). The algorithm uses an assumed mean vertical profile of reflectivity (VPR) within the radar umbrella to adjust estimated near-surface rainrates and reflectivity at those ranges where the lowest radar beam intersects the melting layer, snow, or any hydrometeor distribution different from that near the surface. The CSSA (Seo et al. 2002, 2003) identifies those precipitation areas that are convective in nature; such areas should not contribute to the model of the stratiform VPR, and range correction should not be applied there.

The field evaluation included six real-time sites whose staff were given access to a web page featuring 1-h, 3-h, and 12-h accumulations with and without range correction. The sites were KRTX (Portland OR), KEAX (Pleasant Hill MO), KMPX (Minneapolis MN), KTLX (Twin Lakes OK), KPBZ (Pittsburgh PA), and KRLX (Charleston WV). We also collected data from KLWX (Sterling VA) for local analysis. The evaluators were asked to answer 8 questions based on their impressions of RCA performance over discrete precipitation events.

The radar precipitation estimates were derived from ORPG Build 5 Digital Precipitation Array products, generated at National Weather Service headquarters from base reflectivity data collected in real time from the AWIPS Local Data Monitor. 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 SHEF feed transmitted by the National Weather service.

Based on responses and our own assessment, we also carried out a post-analysis of the data, including a reprocessing of the rainfall estimates to better approximate full integration of RCA/CSSA within the RPG Precipitation Processing System (PPS).

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, is illustrated for each of the evaluation sites in Figs. 1-7. In each figure, the plan-position indicator display at the upper left shows total precipitation for all available hours during a calendar month based on the uncorrected DPA product. The display at upper left shows the total for all range-corrected (DPR) estimates, and that at lower right the difference field between the two. At the lower left, 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 DPR 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 10 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, Fig. 2), though this umbrella features a zone of underestimation to the southeast caused by partial beam blockage due to terrain.

The field for KRTX (Fig. 3) 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 umbrella until late in the study period; rain totals were rather small and there was little evidence of bright-band contamination (KMPX, Fig. 4). 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. 5). 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. 6) 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. 7) 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. Summary of Field Evaluation Results

Reception at fields 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 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. A few of the evaluations included references to some verifying rain gauge data, and the majority of those indicated that range correction yielded closer agreement to the gauge observations.

Some of the field evaluators and we ourselves noted that the degree of adjustment sometimes changed significantly from hour to hour. This can be traced to a convention peculiar to our real-time adjustment procedure, which we were able to correct during post-analysis. One evaluator noted that it was difficult to make an objective real-time assessment since neither our web page nor AWIPS includes a radar/gauge numerical verification feature. Our post analysis includes this objective verification.

4. Objective Evaluation of DPA/DPR Differences

The 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 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 6893 cases for each of the seven sites.

5. Results of Range Correction Evaluation

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, at individual sites and in the sample as a whole. Improvement in terms of RMS error 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 mean absolute and RMS errors 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” (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”to ≥ 0.5” in no more than 3.5% of cases at any one site, and in only 2.7% of cases overall.

To determine that range correction had a positive effect at all ranges from the radar, some statistics for the 1-h accumulations were stratified into three range bands, < 50 km, 50-150 km, and ≥ 150 km, referred to as near-, mid-, and far-range. These subgroups held a total of 1983, 13450, and 8611 cases, respectively (a small number of cases were dropped due to the sorting procedure used)

As shown in Table 4, improvement in terms of mean absolute error and linear correlation coefficient at all ranges, though there is degradation in accuracy at larger ranges, as might be expected. There was general improvement in RMS error at near- and mid-ranges, though at some sites and in the total sample there were instances where little improvement was evident.

6. Combined Effects of Mean-Field Bias and Range Corrections

While it is apparent that range correction had the effect of reducing the generally high bias in the radar estimates evident during this study period, there is still the possibility that a simple mean-field bias (MFB) correction might have had the same effect. We expect that in operations the MFB correction algorithm (Seo et al. 2000), currently operational in AWIPS, will be applied to estimates.

We therefore evaluated both 2004 and 2003 data to assess the effects of MFB correction on both the original estimates (referred to hereafter as DPA) and range-adjusted estimates (hereafter referred to as DPR), in order to examine the effects of the two corrections separately and in combination. The bias correction factor for the radar estimate in each of the identified radar/gauge pairs was based on all contemporaneous gauge and radar-estimated precipitation amounts, excluding the data point in question. The radar and gauge amounts were summed and the bias correction faction calculated by dividing the gauge sum by the radar sum. Gauge and radar data for the calculation were drawn from the current hour and if necessary from previous hours until at least 20 pairs were obtained, a fairly robust approximation of the operational MFB algorithm's time-history function for situations in which gauge data is sparse. Separate MFB correction factors were derived for the DPA and DPR products.

Our analysis of the combined effects of range and MFB corrections focused on 3-h and 24-h amounts, for which verification statistics are less subject to random error than are 1-h amounts. As shown in Table 5, the MFB algorithm had the effect of adjusting the overall radar bias to near 1 for both DPA and DPR. It also appears that for these late-winter and spring cases the MFB and range correction had nearly identical effects on MAE, which was similar for either DPA or DPR with bias adjustment applied. This is probably due to the prevailing reflectivity profile, which featured an elevated melting layer and thus overestimates in the DPA product out to fairly long ranges. We generally observed that the range correction factors were < 1 over most of the umbrella. Therefore, for this set of cases MFB and range correction had similar effects on the original radar estimates.

In situations dominated by lower freezing level heights, with distinct zones of bright-band overestimation and long-range underestimation, the situation is likely different. Our findings for data in the KLWX umbrella during February-March 2003 tend to confirm range correction with MFB correction improves on MFB correction alone in colder conditions. Precipitation events during that period were significantly colder than those at most sites during the 2004 experiment, and our results include some frozen precipitation. Azimuthally-averaged precipitation totals (Fig. 8) indicated pronounced range effects, particularly bright-band enhancement during March (Fig. 8a). Because detection of precipitation beyond about 175 km range was poor during this period, only radar/gauge pairs within that range were included.

As shown in Table 6, MFB correction alone reduced 24-h MAE from 0.21" to 0.19", but combined range and MFB correction reduced the MAE to less than 0.15". Note that range correction alone had no positive impact on bias, since it produced both lowering and raising of estimates at different ranges.

We can conclude that range adjustment did function correctly and had a significant positive impact even in those situations where the predominate range effect was overestimation. Further, based on our results from 2003, it is apparent that range correction has a positive impact distinct from that of MFB correction in cold winter conditions.

7. 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. We will probably advise operational users to avoid attempts at range correction during the period May-September, when it will have little effect.

This evaluation will be continued at most of the radar sites in order to assess the impact of range correction on the radar estimates during the warm season.

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.

8. NEXRAD Technical Advisory Committee Recommendations

A review of the RCA/CSSA project by the NEXRAD Technical Advisory Committee in July 2004 expressed concern with two aspects of the proposed operational implementation, and therefore advised against it. These were the computing time taken by the two algorithms, and the lack of demonstrated evidence that the improvements in precipitation estimation translate to significantly improved stream flow forecasts.

Accordingly, we are taking steps to look for means of optimizing the algorithms for efficiency, and to demonstrate the impact of range correction on stream flow simulations with operational hydrologic models.

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References

Seo, D.-J., J. P. Breidenbach, and E. R. Johnson, 1999: Real-time estimation of mean field bias in radar rainfall data. *J. Hydrology*, **223**, 131-147.

Seo, D.-J., J. Breidenbach, R. Fulton, and D. Miller, 2000: Real-time adjustment of range-dependent biases in WSR-88D rainfall estimates due to nonuniform vertical profiles of reflectivity. *J. Hydrometeorology*, **1**, 222-240.

Seo, D.-J., et al. 2002: Annual report of Office of Hydrologic Development to the Radar Operations Center [available from Office of Hydrologic Development, or through web site at http://www.nws.noaa.gov/oh/hrl/papers/papers.htm#wsr88d].

_____, 2003: Annual report of Office of Hydrologic Development to the Radar Operations Center [available from Office of Hydrologic Development, or through web site at http://www.nws.noaa.gov/oh/hrl/papers/papers.htm#wsr88d].

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. Amounts are in inches.

Site	**# cases**	**Mean Gauge**	**DPA bias**	**DPR bias**	**DPA MAE**	**DPR MAE**	**DPA RMSE**	**DPR RMSE**
KRTX	719	.08	1.60	1.36	.082”	.063	0.119	0.105
KMPX	320	.13	1.43	1.24	.108	.090	0.153	0.167
KTLX	1948	.17	1.37	1.41	.138	.142	0.192	0.272
KEAX	2045	.13	1.56	1.23	.111	.085	0.158	0.162
KRLX	6893	.11	1.68	1.20	.110	.079	0.150	0.136
KPBZ	9406	.11	1.63	1.18	.100	.072	0.137	0.131
KLWX	2984	.12	1.24	0.96	.095	.078	0.140	0.143
ALL	**24315**	**.12**	**1.55**	**1.19**	**.106**	**.081**	**.148**	**.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	**# cases**	**Mean Gauge**	**DPA bias**	**DPR bias**	**DPA MAE**	**DPR MAE**	**DPA RMSE**	**DPR RMSE**
KRTX	105	.27	1.83	1.53	.296	.259	.36	.34
KMPX	---							
KTLX	331	.67	1.20	1.15	.313	.338	.41	.66
KEAX	403	.49	1.43	0.99	.280	.223	.34	.31
KRLX	1525	.35	1.75	1.12	.324	.196	.40	.28
KPBZ	2102	.35	1.73	1.16	.295	.188	.38	.32
KLWX	628	.37	1.38	0.96	.237	.173	.34	.33
ALL	**5105**	**.38**	**1.61**	**1.11**	**.297**	**.203**	**.38**	**.34**

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

Site	**% DPA ERRORS ≥ 0.25**	**% DPR ERRORS ≥ 0.25**	**%CASES WITH DPA ERROR < .05 AND DPR ERROR > 0.1**
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%
ALL	**9.0%**	**6.3%**	**2.7%**

Table 4. Mean absolute error, RMS error, and linear correlation coefficient between 1-h DPA and DPR estimates and gauge observations, stratified by range.

Site	**Mean Absolute Error (Inch)**					
	Near-range		Mid-range		Far-range	
	DPA	DPR	DPA	DPR	DPA	DPR
KRTX	0.0897	0.0718	0.0759	0.0575	0.1002	0.0684
KMPX	0.0891	0.0721	0.1068	0.0746	0.1238	0.1233
KTLX	0.0950	0.0897	0.1314	0.1266	0.1473	0.1600
KEAX	0.0926	0.0689	0.1095	0.0795	0.1212	0.1008
KRLX	0.0888	0.0591	0.1091	0.0708	0.1128	0.0892
KPBZ	0.0781	0.0590	0.0965	0.0623	0.1183	0.1021
KLWX	0.0744	0.0669	0.0843	0.0615	0.1016	0.0875
ALL	**0.0832**	**0.0641**	**0.1029**	**0.0708**	**0.1166**	**0.1027**

Site	**Root Mean Square Error (Inch)**					
	Near-range		Mid-range		Far-range	
	DPA	DPR	DPA	DPR	DPA	DPR
KRTX	0.1231	0.1138	0.1169	0.0997	0.1252	0.0880
KMPX	0.1268	0.1196	0.1514	0.1290	0.1710	0.2269
KTLX	0.1298	0.1591	0.1817	0.2480	0.2045	0.2984
KEAX	0.1269	0.1173	0.1412	0.1301	0.1908	0.2153
KRLX	0.1169	0.0871	0.1452	0.1217	0.1562	0.1511
KPBZ	0.1111	0.0941	0.1299	0.1126	0.1625	0.1794
KLWX	0.1059	0.1114	0.1249	0.1240	0.1483	0.1537
ALL	**0.1158**	**0.1044**	**0.1399**	**0.1312**	**0.1660**	**0.1890**

Site	**Linear Correlation Coefficient**					
	Near-range		Mid-range		Far-range	
	DPA	DPR	DPA	DPR	DPA	DPR
KRTX	0.5409	0.5553	0.5499	0.5994	0.4063	0.4568
KMPX	0.7290	0.8198	0.6354	0.6856	0.4912	0.5213
KTLX	0.6136	0.6491	0.5851	0.6419	0.4786	0.4946
KEAX	0.7406	0.8063	0.6531	0.6886	0.5015	0.5474
KRLX	0.5958	0.6716	0.5532	0.6012	0.4074	0.4576
KPBZ	0.5764	0.6092	0.5791	0.6414	0.4290	0.4592
KLWX	0.6194	0.5983	0.5813	0.6448	0.4519	0.4647
ALL	**0.6336**	**0.6225**	**0.5693**	**0.5785**	**0.4550**	**0.4673**

Table 5. Effects of MFB adjustment, range adjustment, and both adjustments on 3-hour precipitation amount verification scores, March-May 2004. Site KMPX had < 10 such observation sequences and is not included.

Site	**# cases**	**Mean Gauge**	**DPA bias**	**DPR bias**	**DPA+ MFB bias**	**DPR+ MFB bias**	**DPA MAE**	**DPR MAE**	**DPA+ MFB MAE**	**DPR+ MFB MAE**
KRTX	103	.27	1.83	1.53	1.21	1.10	.295	.259	.109	.101
KMPX	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------
KTLX	326	.67	1.20	1.15	0.95	0.93	.313	.338	.233	.242
KEAX	403	.49	1.43	0.99	1.02	1.00	.280	.223	.182	.186
KRLX	1525	.35	1.75	1.12	1.02	0.99	.324	.196	.156	.158
KPBZ	2099	.35	1.73	1.16	1.02	1.00	.295	.188	.152	.147
KLWX	627	.37	1.38	0.96	1.05	1.01	.237	.173	.169	.151

Table 6. As in Tables 5-6, except 24-h precipitation verification statistics for the KLWX umbrella during February-March 2003, radar/gauge pairs within 175 km of the radar.

Site	**# cases**	**Mean Gauge**	**DPA bias**	**DPR bias**	**DPA+ MFB bias**	**DPR+ MFB bias**	**DPA MAE**	**DPR MAE**	**DPA+ MFB MAE**	**DPR+ MFB MAE**
KLWX	1177	.44	0.73	0.63	0.90	0.92	.209	.205	.185	.146

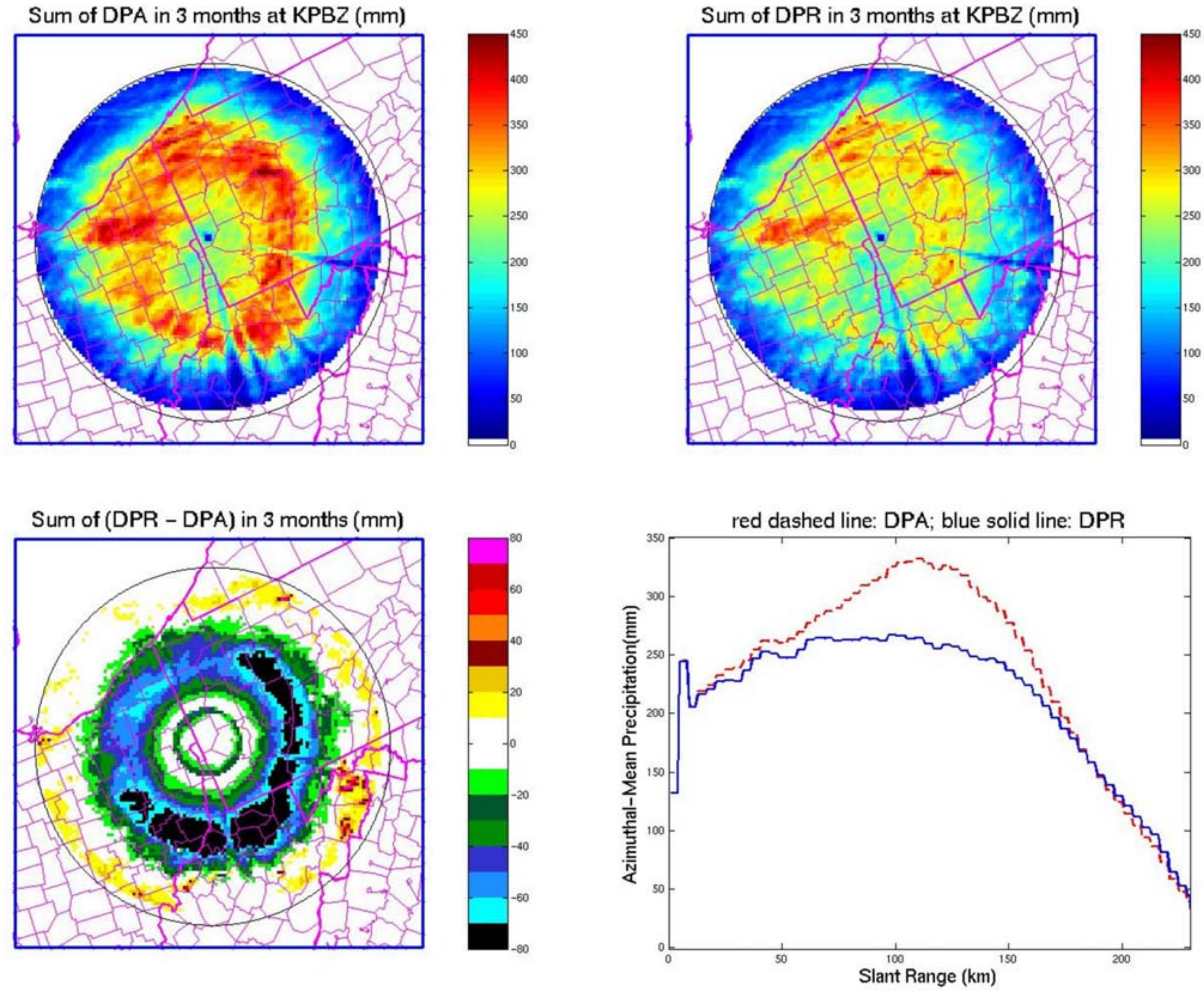


Figure 1. Sum of DPA estimates (top-left), DPR estimates (top right), difference (DPR - DPA) (bottom left), and azimuthally-averaged precipitation vs. slant range (bottom right) in KPBZ umbrella over 3 months (March - May, 2004). Only those cases with radar observations were included. All amounts are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

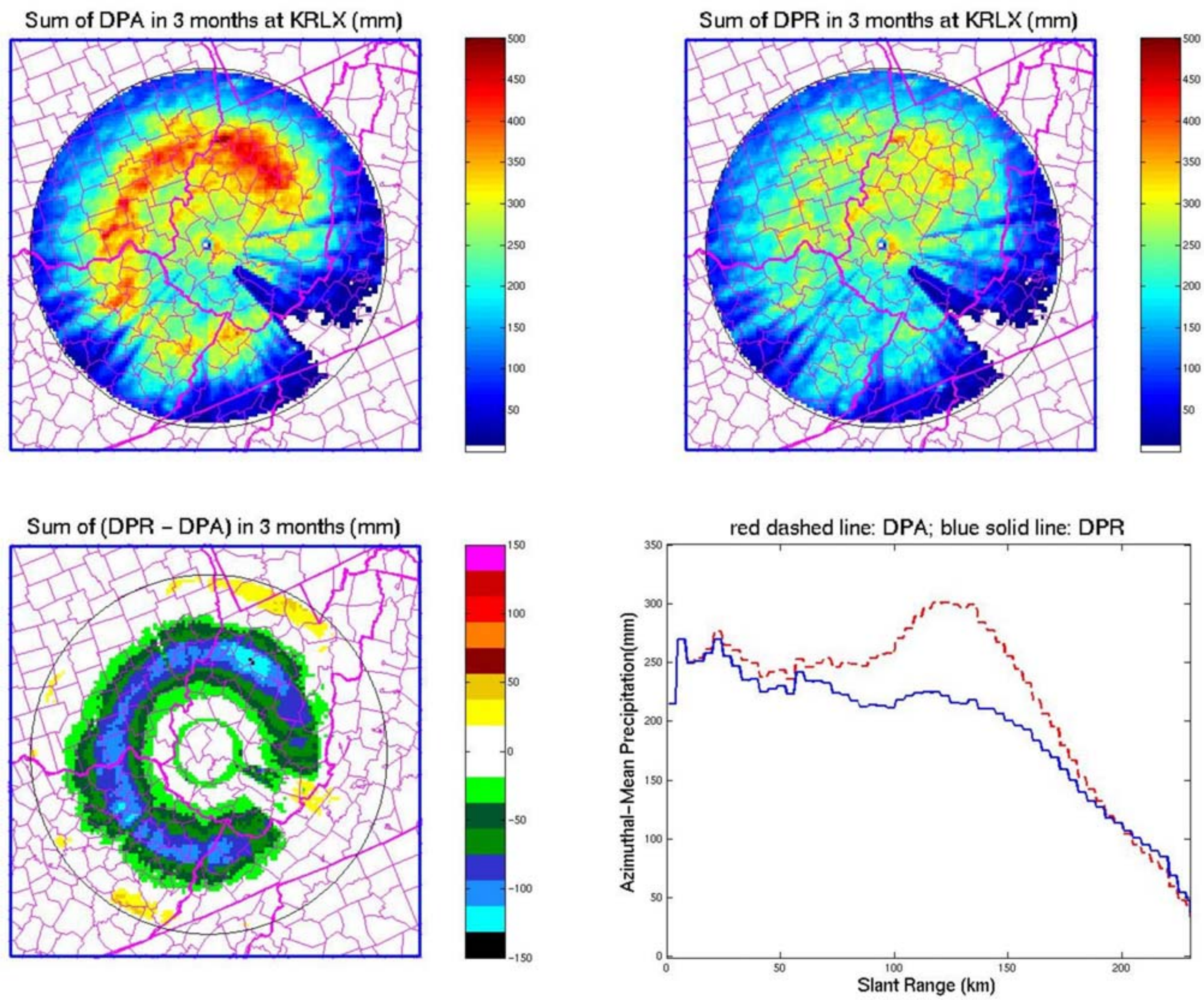


Figure 2. As in Fig. 1,but for KRLX umbrella.

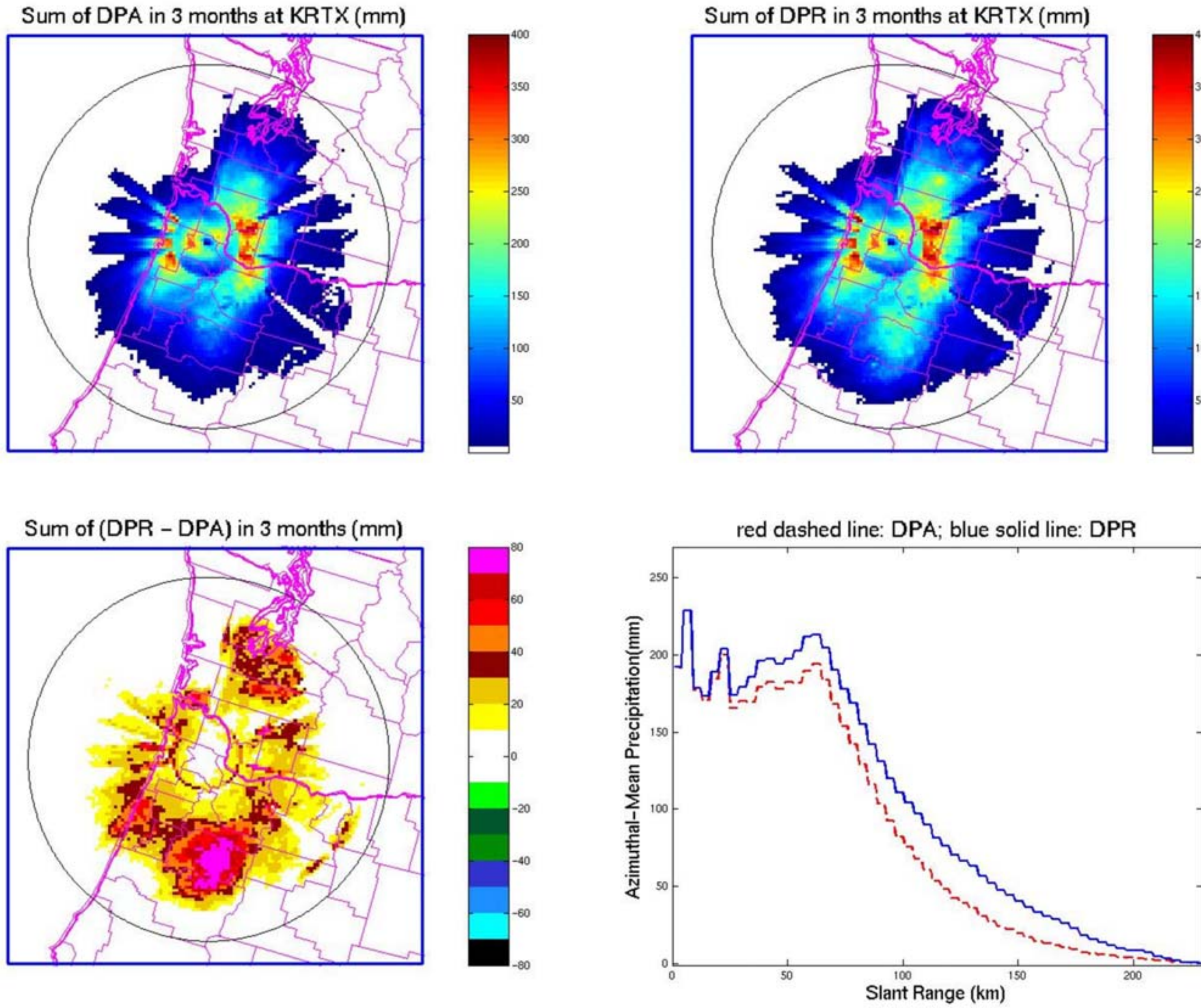


Figure 3. As in Fig. 1, but for KRTX umbrella.

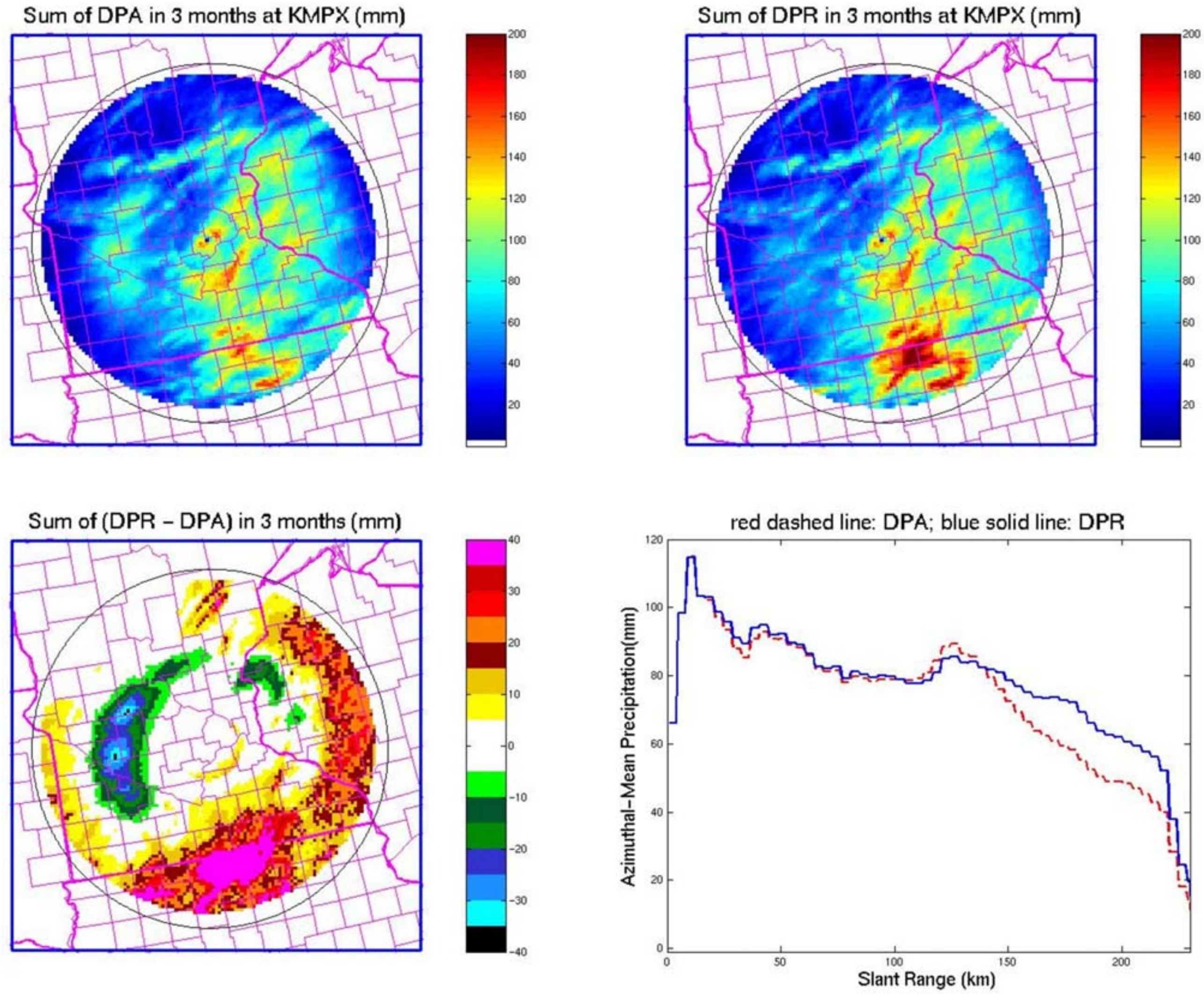


Figure 4. As in Fig. 1, but for KMPX umbrella

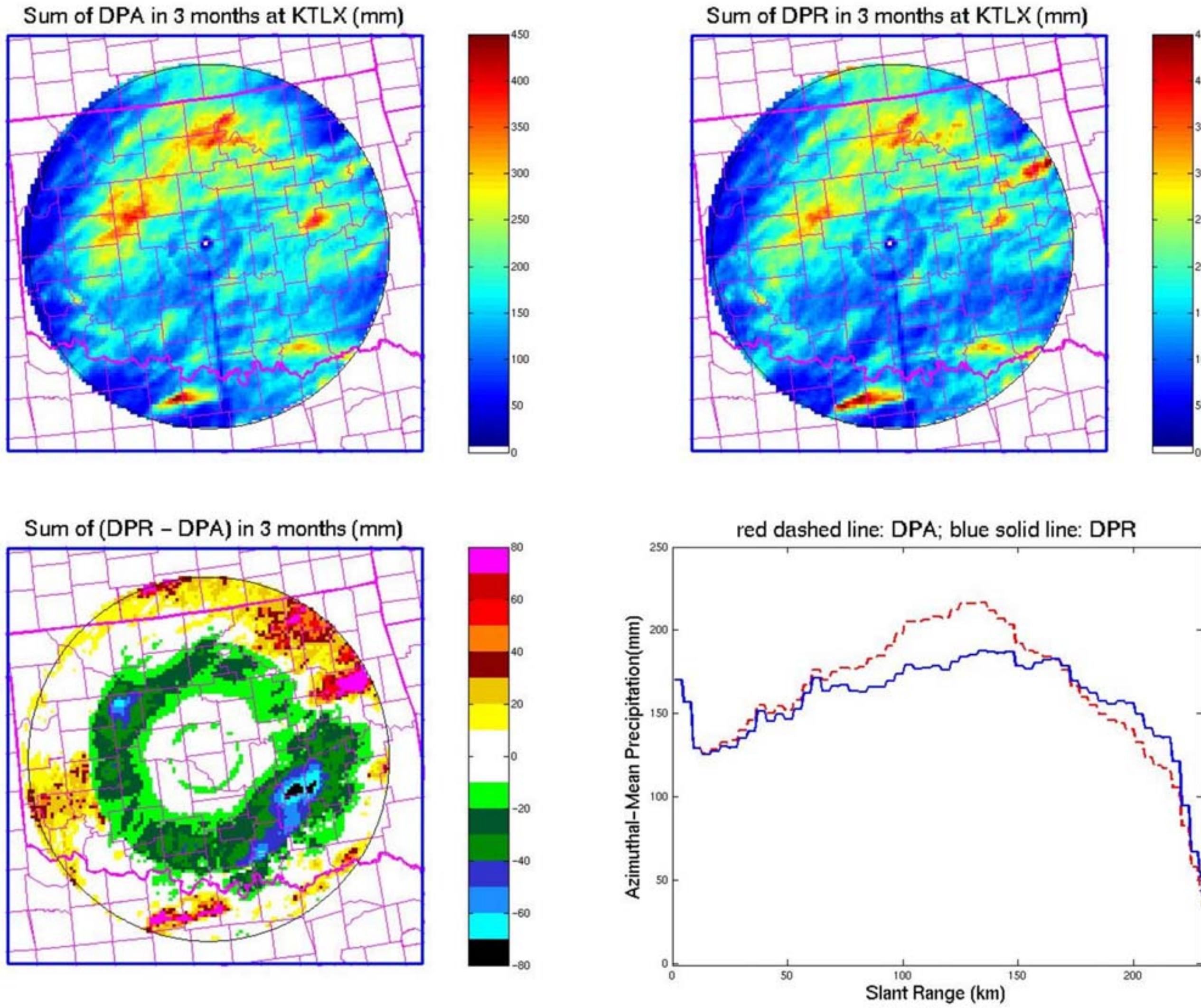


Figure 5. As in Fig. 1, but for KTLX umbrella

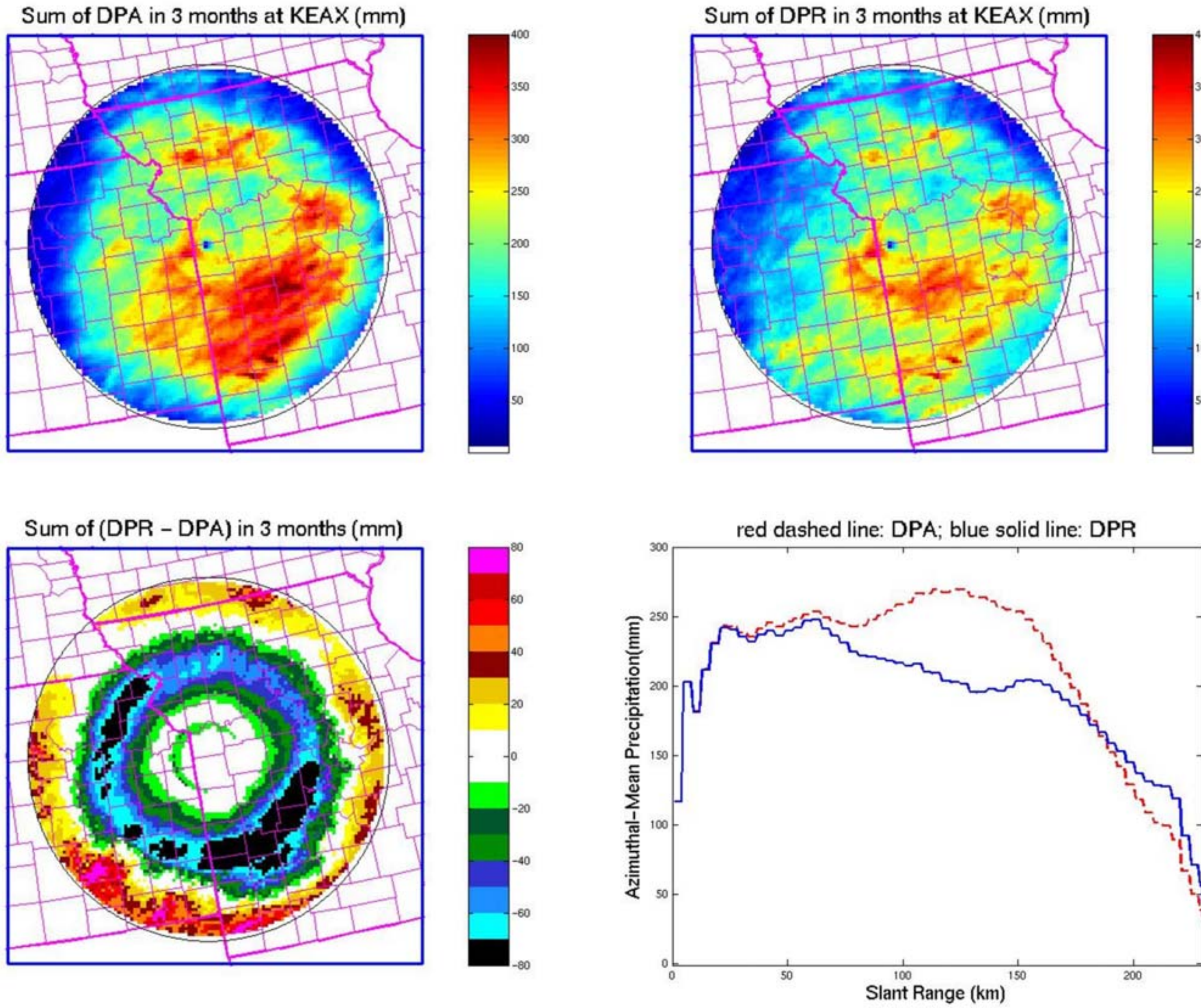


Figure 6. As in Fig. 1, but for KEAX umbrella.

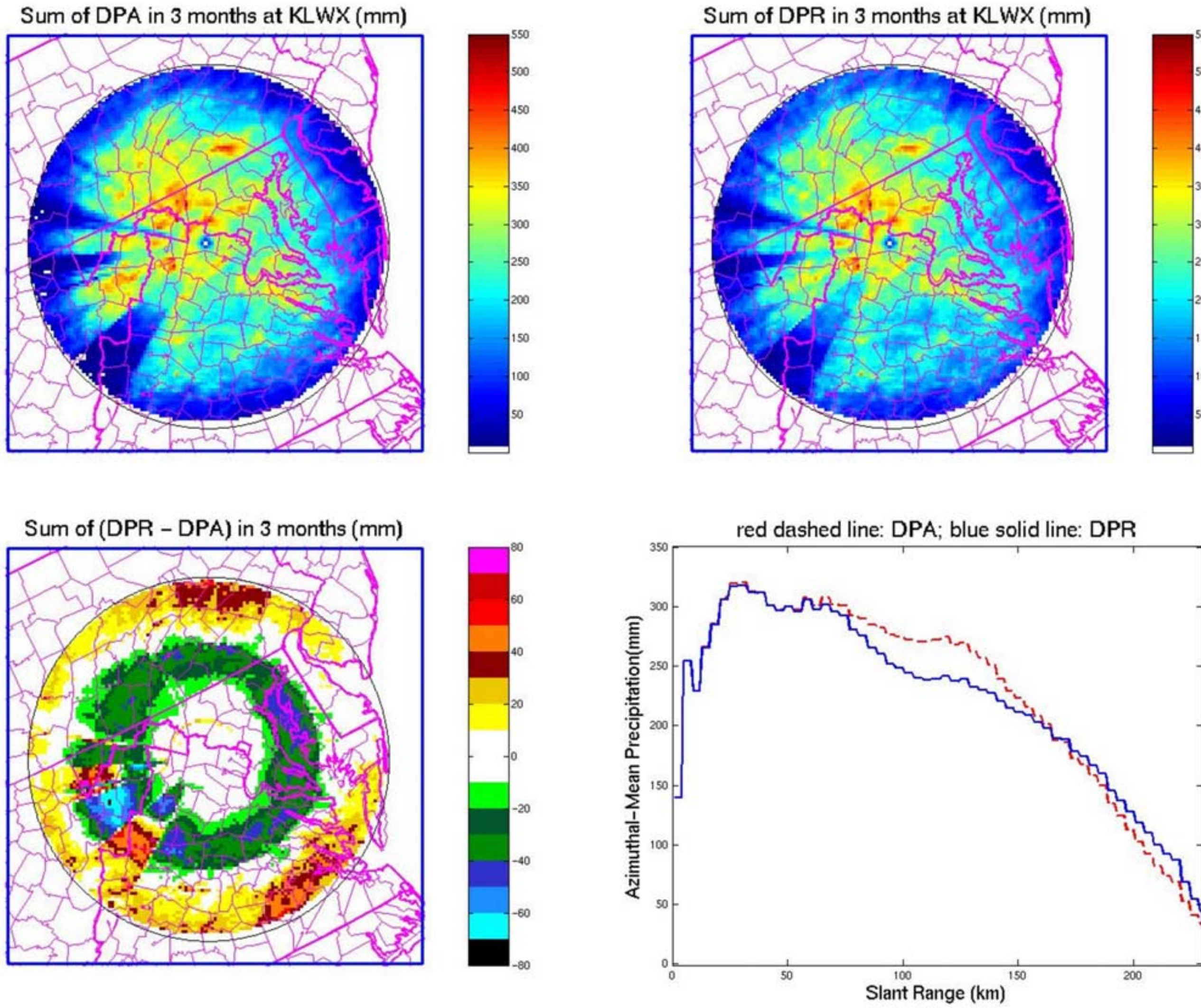
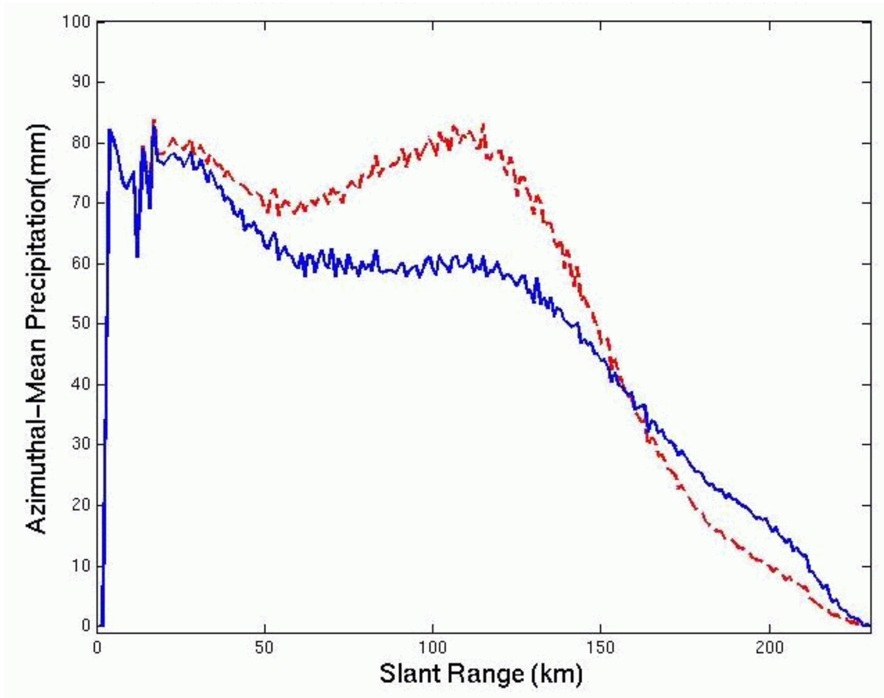
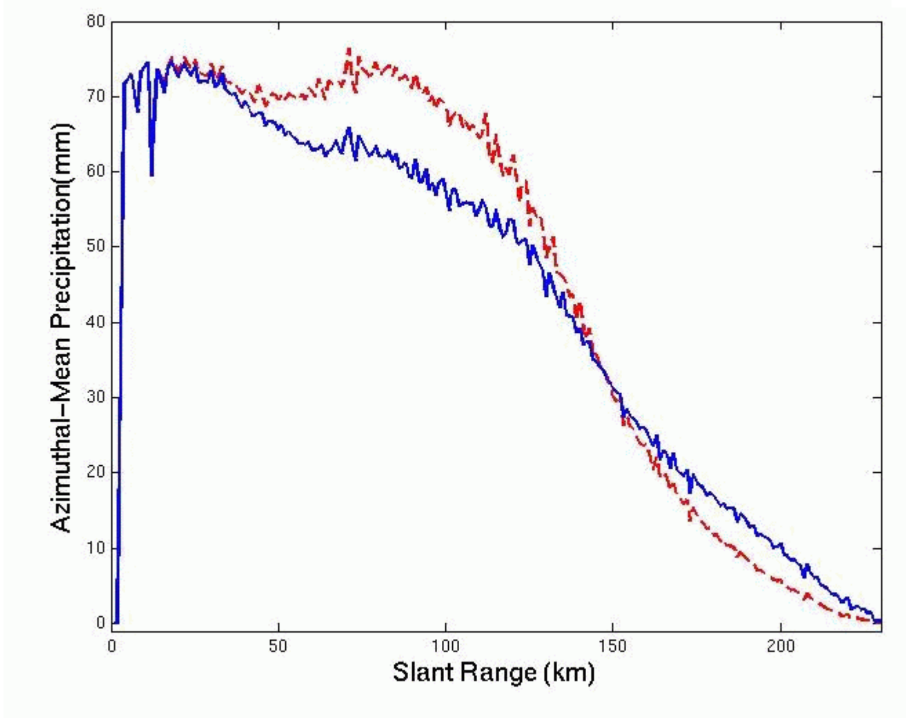


Figure 7. As in Fig. 1, but for KLWX umbrella.



a



b

Figure 8. Azimuthally-averaged precipitation during (a) March 2003 and (b) February 2003 within the KLWX umbrella. Red trace is original DPA estimate, solid blue trace is range-corrected estimate