FY 2009 (Final) Report: June 2008 – May 2009

Radar Operations Center – Office of Hydrologic Development
Memorandum of Understanding

Dual-polarization solutions to QPE in partial radar beam blockage
Snow observations collection over northern Indiana and Illinois

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Executive Summary

This report summarizes work by the NWS Office of Hydrological Development (OHD) on a Memorandum of Understanding (MOU) with the NWS Radar Operations Center (ROC) during the one-year period June 2008 – May 2009. Work was on two tasks:

- Task 1: Dual-polarization solutions to Quantitative Precipitation Estimation (QPE) in presence of partial radar beam blockage;

- Task 2: Collection of snowfall reports in the vicinity of the Great Lakes for development of a dual-polarization radar snowfall algorithm by NSSL.

Under Task 1, work has proceeded on evaluating the potential use of the dual-polarization specific differential phase (Kdp) field as a robust estimator of rainfall in areas affected by partial beam blockage. The overall goal was to assess the quality of the R(Kdp) algorithm in areas of known partial beam blockage against the currently-operational, horizontal polarization reflectivity R(Zh) algorithm. Our approach was to compare estimates determined from each methodology (the latter being prepared both unenhanced and enhanced to compensate/correct for partial beam blockage) against verification fields prepared from a combination of rain gauge and WSR-88D radar data.

At present, there are only limited archives of readily-accessible dual-polarization, S-band radar data collected in mountainous terrain. However, we located suitable data from two field experiments conducted by the NCAR Earth Observing Laboratory (EOL) with its S-band unit (S-Pol): in northeastern Colorado near Boulder during June-August 2006 (the Refractivity Experiment for H_2O Research and Collaborative Operational Technology Transfer, or REFRACTT, Roberts et al. 2008); and in central Oregon in November-December 2001 (IMPROVE II, Improvement of Microphysical Parameterization through Observational Verification Experiment, Houze and Medina 2002). By employing information on radar siting and terrain applied in a ROC algorithm for estimating beam blockage at WSR-88D sites, we were able to estimate percent terrain blockage for multiple low antenna elevation angles for both these S-Pol deployments. In both instances, we found sectors of the low-elevation sweeps that were partially blocked (10-90 %) and suitable for our study, as well as sectors that were unblocked or almost completely blocked.

For the Oregon deployment, we were able to derive rainfall estimates from all the above methodologies and compare them to each other; however, due to the time of year and location of the IMPACT S-Pol deployment, the R(Kdp) fields were not collected under conditions for which they would normally be employed operationally. Also, we have not yet been successful in generating verification fields that we feel are of sufficient quality to use as the basis for statistical comparison.

For the Colorado deployment during the REFRACTT experiment, conditions were favorable (i.e. mostly convective precipitation) for operational application of the R(Kdp) field. In this instance, we were able to perform statistical comparison with a satisfactory, gauge-radar verification dataset – one that had been prepared during routine operations by the Missouri Basin River Forecast Center. The verification field incorporated data from the Denver WSR-88D unit, which has an unobstructed view of the areas which were partially blocked relative to the S-pol radar at Boulder. Though we generated rainfall estimates from several lower-level elevations, all the statistical results presented here were from data from the 0.5° antenna elevation.

The results from Colorado indicate that unenhanced precipitation amounts derived from horizontal polarization were substantially underestimated in areas of large beam blockage, as might be expected. However, augmenting the returned power proportionally to the amount of blockage yielded reliable estimates, even in sectors with significant blockage (up to 90%, and perhaps even greater). The R(Kdp) estimates appeared to become biased low in areas of partial beam blockage, suggesting sensitivity to terrain blockage, as well. This finding is in contrast to prevalent thinking regarding the behavior of the R(Kdp) field. It is possible that this result was due in part to application of the algorithm to all hydrometeor types; current plans are to use the R(Kdp) operationally only in large-drop or rain/hail situations.

In Task 2 of the agreement, work has ensued on collection of ground snowfall observations in northern Indiana and Illinois. We have created datasets with daily and subdaily snow and liquid amount reports from five events during the winter of 2007-2008, as requested by NSSL. The reports are from FAA and NWS ASOS sites and from cooperative observer reports within the CoCoRaHS network. Data from eleven ASOS and approximately 330 CoCoRaHS sites have been gathered and reformatted for ease of collocation with radar estimates. However, only a limited number of subdaily snowfall reports (generally 6-h totals) were obtained from four regularly-staffed ASOS sites, and from a few CoCoRaHS narrative reports.

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Task 1: Dual-polarization solutions to QPE in partial radar beam blockage

This report covers progress on MOU Task 1 during the period June 2008-June 2009

We have made progress in several areas during the past year in our work on evaluating radar-estimated rainfall derived from the dual-polarized, specific differential phase field (R(Kdp)), and comparison of that to rainfall estimates from other horizontally-polarized methodologies, in the presence of partial beam blockage. That progress was in the following principal areas: **(1) coding/enhancing our processing system** (in radar-QPE estimation from the various methodologies; integration of terrain-blockage information at the locations of the S-Pol radar-sample bins; and generation of verification fields from rain gauge and WSR-88D radar data); **(2) identifying and running suitable cases** in our two S-Pol deployment areas, namely west-central **Oregon**, west of the Cascades, during late fall-early winter 2001; and north-central **Colorado** near Boulder, just east of the Rockies, during summer 2006; and **(3) analyzing the results** by comparison of the QPE fields derived from the various methodologies against each other and against the verification fields.

Progress on enhancing processing system/coding

During the past year (i.e. June 2008 – June 2009), the following enhancements/ improvements have been made to our in-house, data-processing and analysis system:

- We streamlined the process of ingesting base S-Pol radar fields in their native ("SWP") format and reprocessing them into the format (NetCDF) needed for ingest into our rainfall analysis program. In doing so, we built in versatility to account for variations in format and content of the base S-Pol data, such as different base fields ingested; variations in range out to which data sampled; and sector scan vs. full scan processing.

- We revamped the logic of our code for preparation of the Kdp field from Φdp to make it consistent with the latest version of Alexander Ryzhkov's Dual Pole QPE algorithm (i.e. the version that is slated for national implementation in WSR-88D operations, beginning with RPG Build 12). After implementing filters and performing testing, we now feel confident that we are generating good, "clean" fields of Kdp from which we can generate consistent and accurate rainfall rates and accumulations (R(Kdp)).

- We revised the logic for the sequence of mapping rain rates to our fixed, polar analysis grid (i.e. a polar grid of 1-degree azimuthal resolution, analogous to that used in WSR-88D operations). In the previous methodology, incoming, base radials were moved or relocated to the centers of the fixed grid slots in which they fell before rain rates and accumulations were determined (i.e. displacement could be up to 0.5^0); now rain rates are determined first and then distributed to the fixed, polar grid via a proportional-weighting technique based on amount of overlap.

- We extracted the percentage-blockage-as-a-function-of-range information from the RPG-compatible 'linear buffers' created (at our request) by the ROC at the exact locations (lat/lon/hgt) of the two S-Pol sites (Oregon; Colorado). After reformatting, we utilized this data to generate blockage maps for each of the lower-level elevations (i.e. below 2.5^0) at which we processed sample data, as determined by the volume coverage patterns (VCPs) in use at the time at the two sites (see Figs 1 & 2).

- We implemented logic to enhance traditional precipitation estimates derived from the Z-R relationship proportionally to percentage of beam blockage, in a manner similar to that employed in the operational, WSR-88D Precipitation Preprocessing System (PPS), though with corrections allowed to a higher threshold. The formula for enhancement is:

$$\text{Blk_Fact} = \begin{cases} 1.0 / (1.0 - B) & (B < \text{Bthreshold}) \\ 1.0 / (1.0 - \text{Bthreshold}) & (B >= \text{Bthreshold}) \end{cases}$$

$$Z_{adj} = 10^{**(DBZ / 10.)} * \text{Blk_Fact}$$

$$R_{enh} = R(Z_{adj}) = (Z_{adj}/a)^{**(1/b)}$$

Where:

B is the fractional beam blockage (to nearest .01) at a given sample bin location;
$B_{threshold}$ is the upper threshold of beam blockage for which a correction is applied;
Bl_Fact is the blockage factor by which a bin's reflectivity power is enhanced;
Z_{ADJ} is the blockage-adjusted reflectivity power (mm^6/m^3);
R_{enh} is the enhanced rainfall rate, compensating for blockage (mm/hr);
a,b are the multiplicative & power coefficients of the Z-R relationship (300.; 1.4, respectively)

Notes:

Each bin's reflectivity-power is enhanced proportionally to its fractional beam blockage, B;
B cannot exceed the designated threshold, which we experimented with up to values of 0.99;
At our ultimately-determined upper threshold of 0.9, the reflectivity power enhancement was:
1.0/[1.0 – 0.9] = 1.0/[0.1] = 10.0;
In the R_{enh} notation, 'enh' indicates the maximum blockage factor corrected for (e.g. R_{90});
We also generated unenhanced rainfall fields from the Z-R relationship, expressed as R_0

- We implemented methodologies for gathering and processing verification data from several sources, including: a) Digital Precipitation Array (DPA) unbiased, 1-hourly accumulation products from nearby WSR-88D stations; b) "Stage II" gauge-only and gauge-radar accumulation grids, generated by a version of the AWIPS Multisensor Precipitation Estimator (MPE) function implemented at the National Centers for Environmental Prediction (NCEP); and c) "Stage IV" mosaicked, gauge-radar accumulation grids generated at River Forecast Centers and mosaicked at NCEP. These verification fields were prepared on the ~4 km x 4 km, polar-stereographic, Hydrologic Research and Analysis Projection (HRAP) grid system often used in NWS hydrometeorological operations.

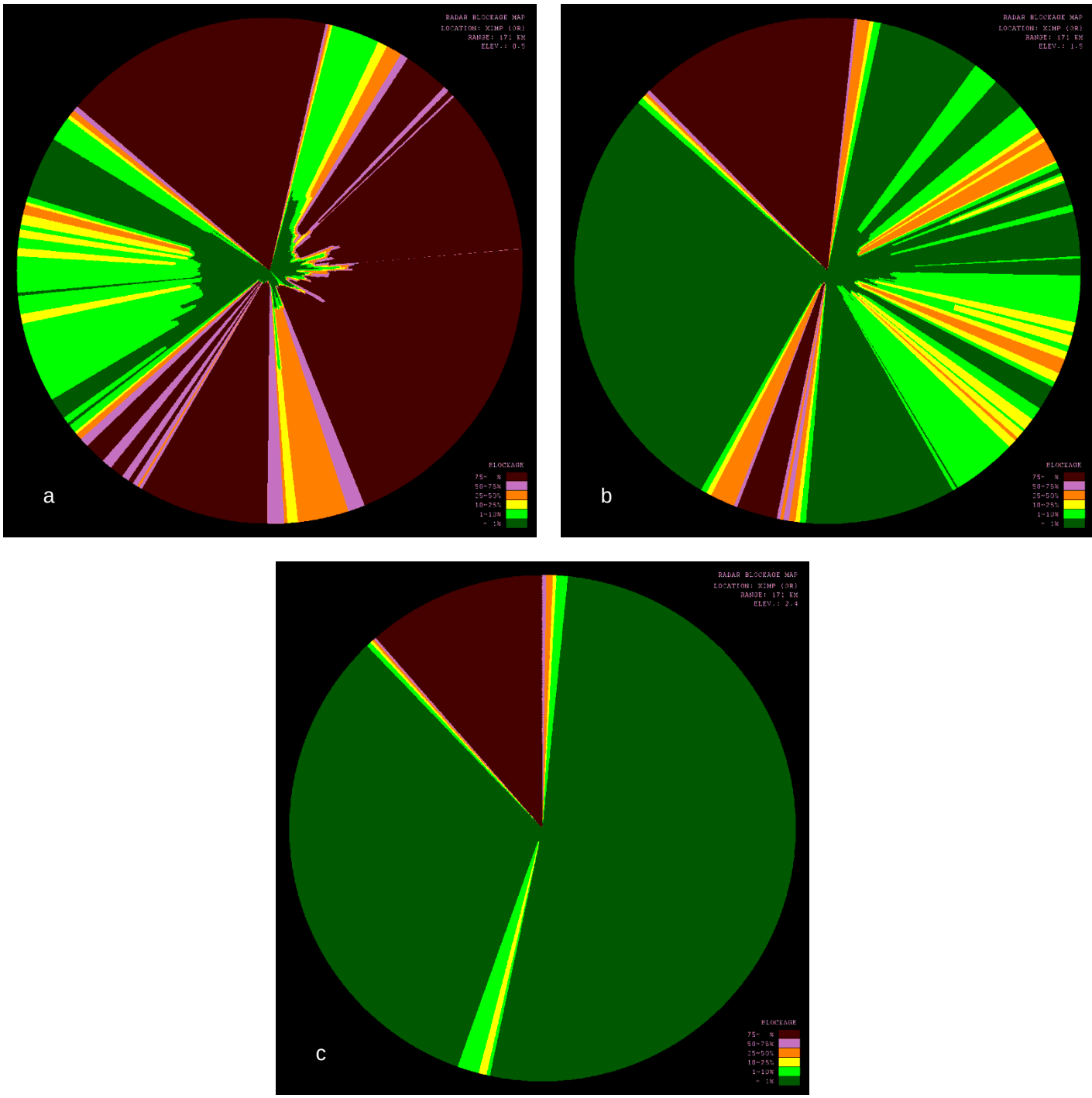

Figure 1. Beam Blockage for **Oregon** S-Pol site at: a) 0.5^0; b) 1.5^0; c) 2.4^0. Color levels are: dark green, <1%; light green: 1-10%; yellow: 10-25%; orange: 25-50%; violet: 50-75%; purple: >75%

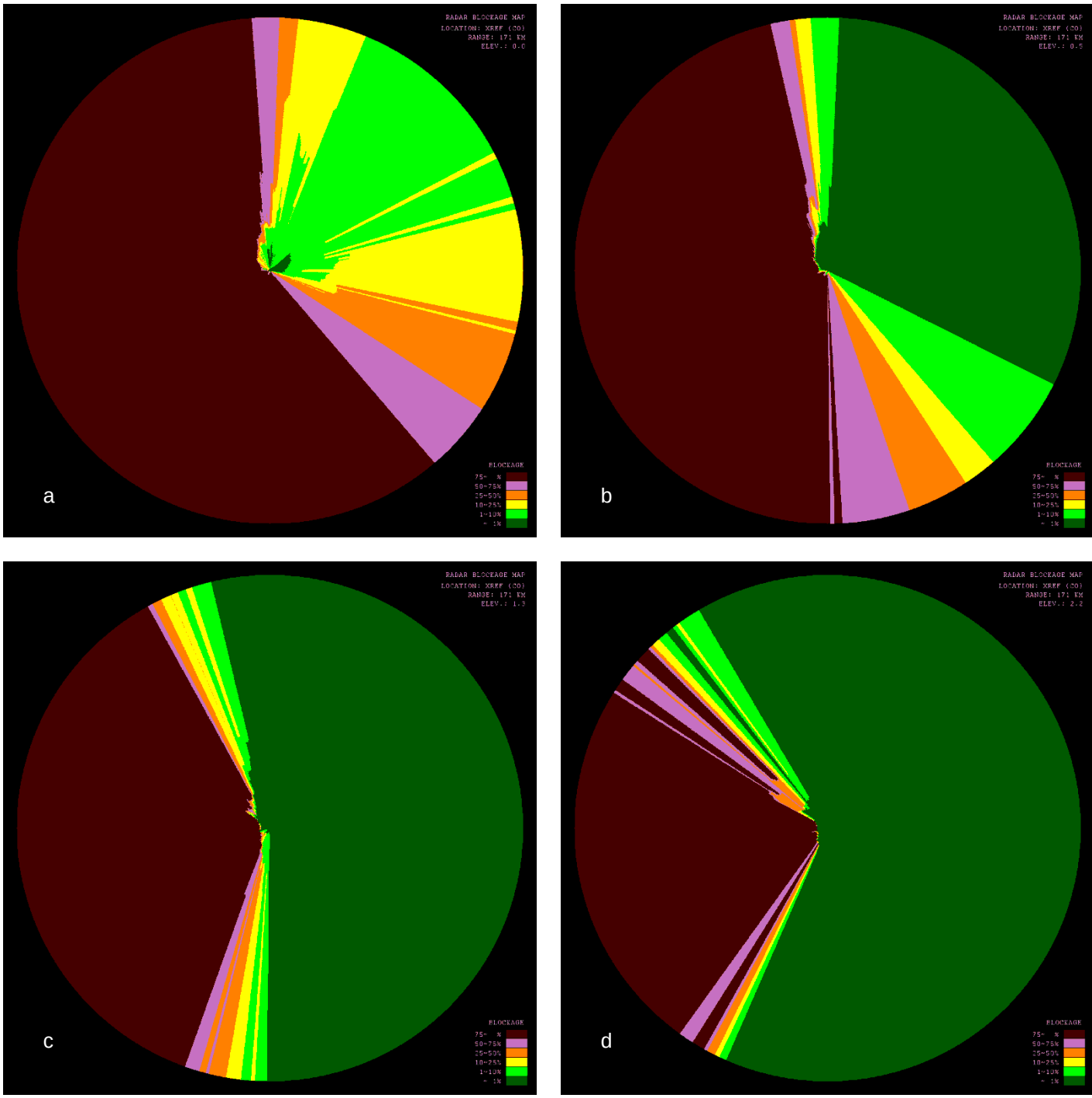

Figure 2. Beam Blockage for **Colorado** S-Pol site at: a) 0.0^0; b) 0.5^0; c) 1.3^0; d) 2.2^0. Color levels same as Fig 1:

- We implemented routines for translation of our S-Pol accumulation fields, determined from the various methodologies (above), to the same ~4 km x 4 km HRAP grid system. We then generated code to perform various statistical analysis measures, including rainfall ratio, correlation coefficient, and error standard deviation, on these QPE fields against the verification fields at the HRAP grid points.

Progress on Data Collection and Running Cases

During the past year we have collected and processed the following data:

- Base S-Pol (dual pol) data:
    - For both of the sitings of the S-Pol radar in regions with significant beam blockage used in our study (i.e. OREGON and COLORADO), we perused reflectivity fields on the S-Pol web site for periods with apparent precipitation, collected the base, dual-pol data for those periods, and performed a preliminary assessment as to whether non-trivial precipitation had, indeed, occurred. For those periods deemed worthwhile, we proceeded to generate QPE fields by the various methodologies, including:
        - Determination of 1-hourly (approximately "clock-hourly") QPEs from Specific Differential Phase, or $R(K_{dp})$, and from Base Reflectivity, both unadjusted, denoted $R(Z_0)$, and adjusted to compensate for beam blockage. Enhancement was conducted up to levels including 80%, 90% and 99%, denoted $R(Z_{80})$, $R(Z_{90})$ and $R(Z_{99})$ respectively. Ultimately, concentration was on the 90% enhancement level. The principal elevation angle at which QPEs were generated was 0.5^0, though in some instances, they were generated at additional low-level elevations (from 0.0^0 to 2.4^0, depending on VCP);
        - Determination of multi-hour accumulations for a subset of the above, that is, $R(Z_0)$; ($R(Z_{80})$; $R(Z_{99})$; and $R(K_{dp})$, for periods of 3-6 hour duration, at the same antenna elevations as above.
    - For selected periods for both Oregon and Colorado, the above S-Pol accumulation products were translated to the same grid (HRAP) as the verification data, to allow statistical comparison.
        - For complete listings of the OREGON and COLORADO S-Pol cases processed to date, see the Appendix. Note that the Appendix details the cases for which QPEs were generated (on the S-Pol grid), which is a broader set than that for which statistical verification analyses were eventually performed (on the HRAP grid).

- Verification data:
    - For periods corresponding to those over which we processed QPEs via the various methodologies described above, we generated verification products on the HRAP grid, from WSR-88D DPA products and from NCEP Stage IV

RFC-based multisensor input files. For a complete listing of the Verification datasets processed to date, see Appendix.

Progress on Analysis

Approach

Our primary analysis approach was to compare the precipitation accumulations prepared via the various methodologies (described above) against the corresponding verification fields on the ~4 km x 4 km HRAP grid, both visually and statistically. The QPE fields we chose for analysis were R(Kdp) via Alexander. Ryzhkov's methodology and traditional R(Zh), both unenhanced and enhanced to compensate for blockage. The R(Kdp) equation is the latest one implemented in the operational RPG Build 12. For experimental purposes and visual comparison, we went as high as to compensate for 99% blockage, but for statistical analysis (see below), we still compensated for blockage up to 99% but chose 90% as the upper limit at which blockage correction would be applied, that is, $R(Z_{90})$. It is noted that in WSR-88D operations, the blockage threshold for processing R(Zh) is adaptable, with a default of 50%, which is almost universally applied in NWS operations. We chose the higher, 99% blockage/90% correction thresholds for our study to get a sense for how this corrective technique might perform when taken to near its limits of applicability, and to compare its effectiveness under nearly complete blockage conditions to the R(Kdp) methodology under the same circumstances.

Preliminary assessment

In general, it has proven rather challenging to find the combination of circumstances ideally needed for this study – i.e. where rainfall is due primarily to large drops or hail simultaneously with where sampling is occurring in conditions of partial terrain blockage of the radar beam. Overall, we have had considerably more success in the processing and analysis of our Colorado cases (from the summer of 2006) than our Oregon cases (from late fall-early winter of 2001):

- In **Oregon**, we were able to derive coherent fields of R(Kdp) but, as Figs 3-5 illustrate, these were in fall-winter conditions where a brightband was typically present, as evidenced by the doughnut-like precipitation feature in the R(Zh) fields, both unenhanced and enhanced. Hence, precipitation at ranges beyond the doughnut feature at each elevation is likely to be dry snow, melting snow flakes, or small rain drops. These are all hydrometeor types for which R(Kdp) was not calibrated and is *not* preferred as an estimator. It does appear, though (see Figs 3d, 4d & 5d), that the R(Kdp) field was able to discern non-trivial precipitation out to considerably greater ranges than R(Zh). Hence, R(Kdp) may have some value for use in small droplet/frozen precip situations, particularly when traditional estimation methods cannot "see" above the brightband. It is as yet unclear, however, how accurate this estimation technique may be under these circumstances; in particular, we suspect it

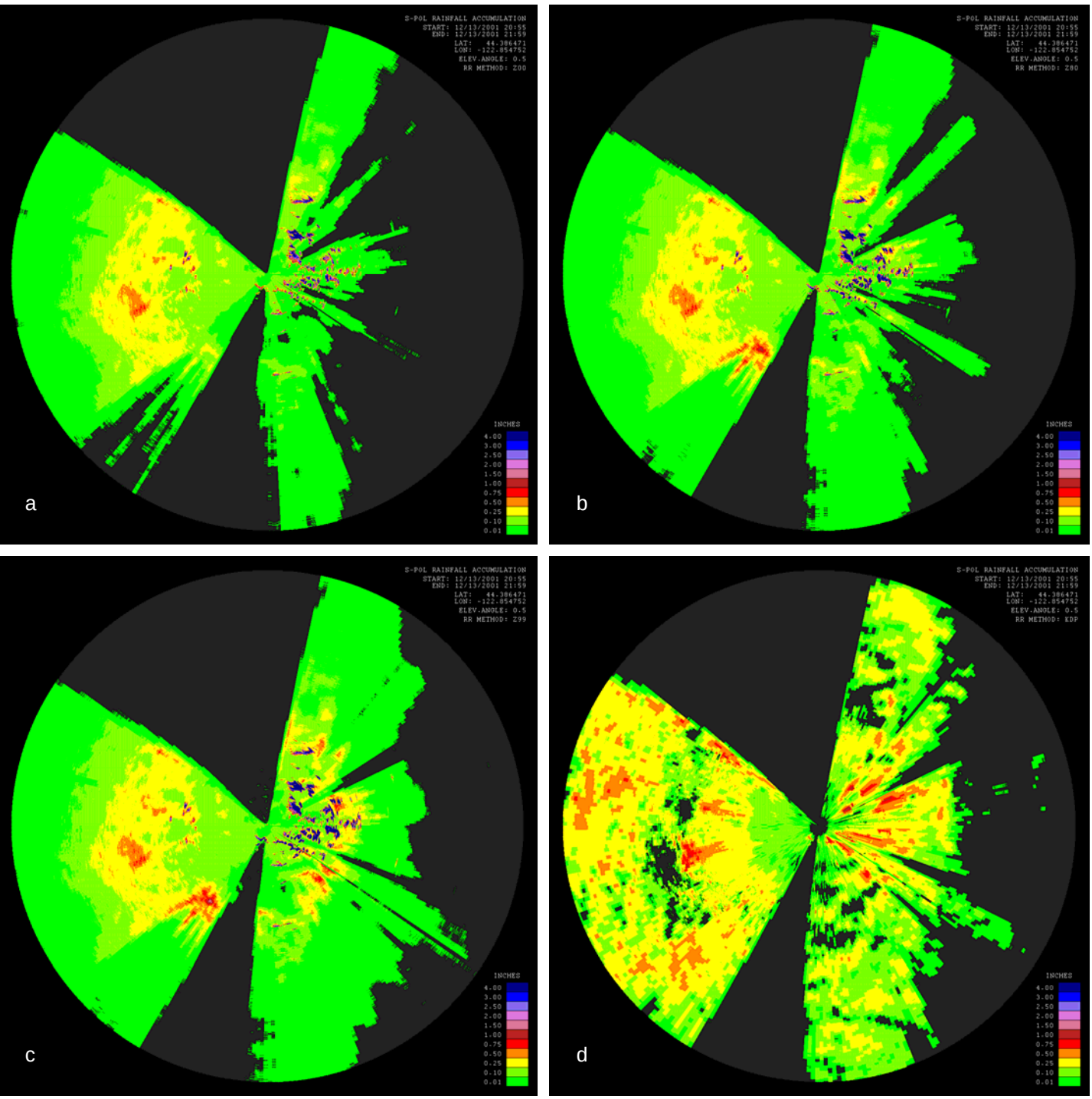

Figure 3. 1-hour accumulations at 0.5^0 for **Oregon** S-Pol site on 12/13/2001, 21-22z : a) $R(Z_0)$; b) $(R(Z_{80})$; c) $R(Z_{99})$; and d) $R(K_{dp})$

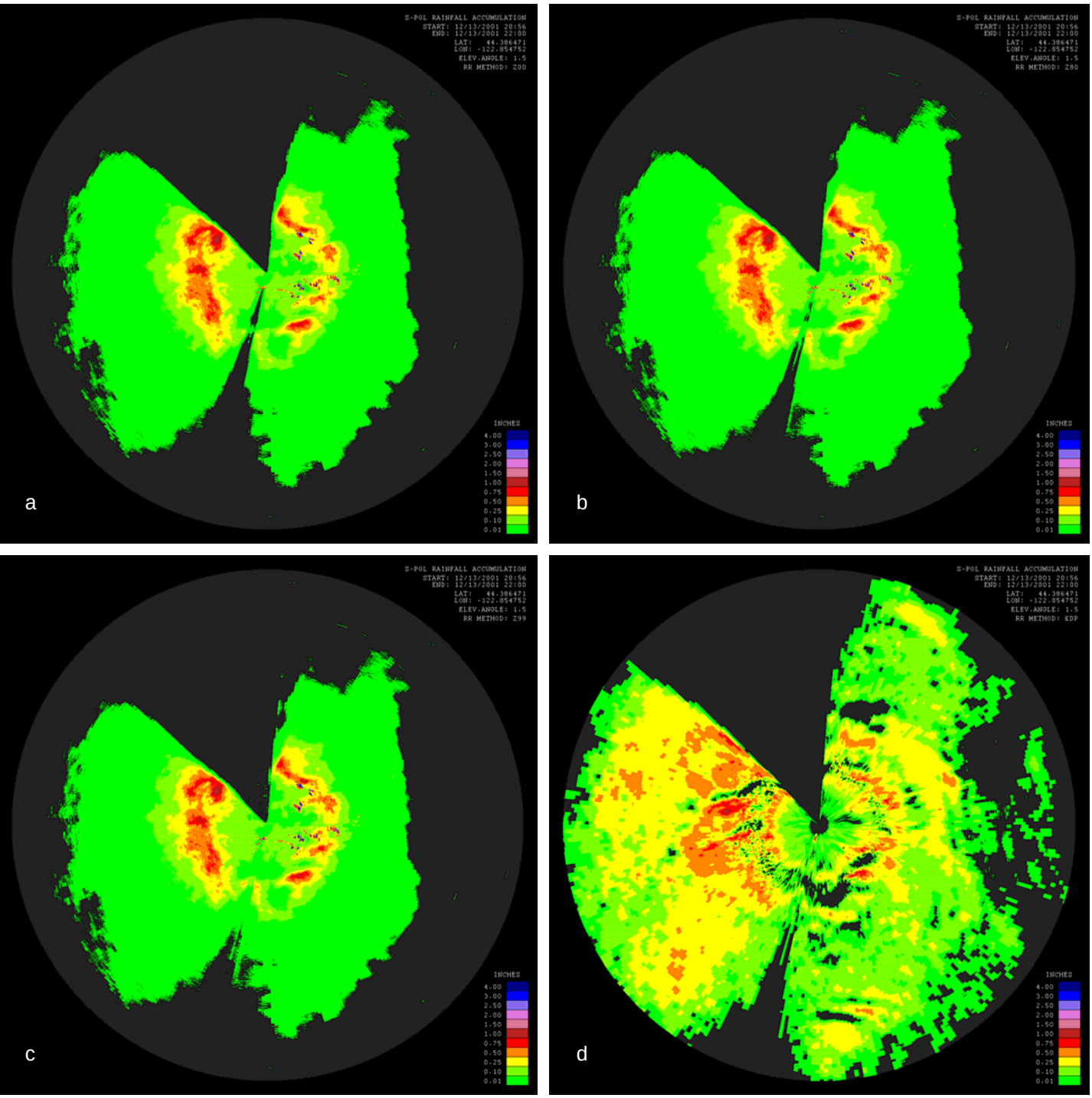

Figure 4. Same as Fig 3 except at 1.5^0

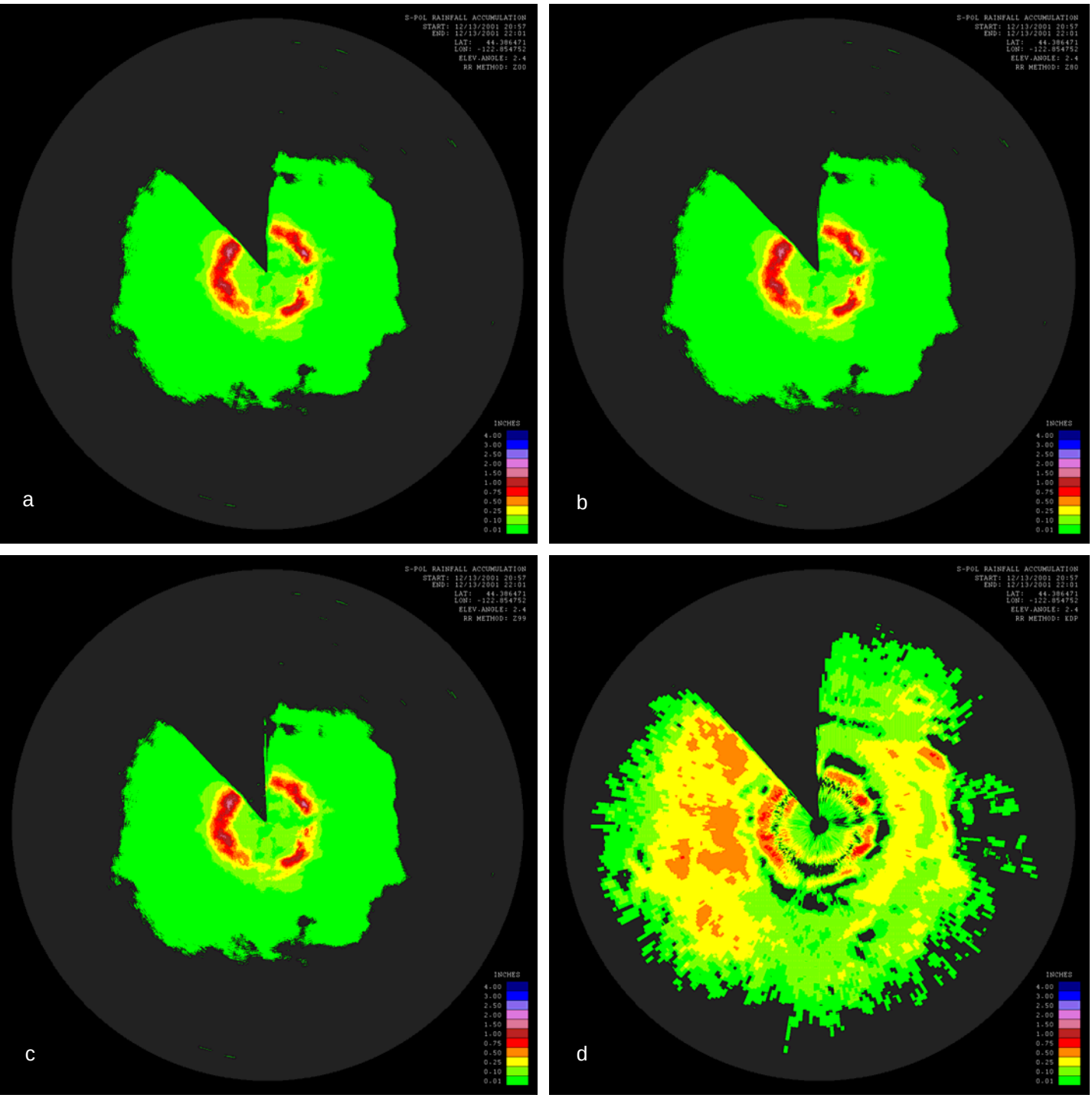

Figure 5. Same as Fig 3 except at 2.4^0

may be yielding overestimates (unfortunately, we have not yet been able to compare these estimates against verification fields – see below)

- We have as yet been unsuccessful in generating what we consider to be suitable verification fields for the Oregon S-Pol deployment in Oregon,. This is partially a consequence of the fact that the local River Forecast Center (i.e. NWRFC) was not running the Multisensor Precipitation Estimator (MPE) application (or similar) at the time of the S-Pol deployment to generate Stage-II, III or IV precipitation fields. We are presently pursuing alternative approaches – e.g. based on PRISM monthly total precipitation , disaggregated to hourly amounts by reference to radar and/or gauge reports– to attempt to generate useful verification fields.

- In **Colorado**, observations were made during the summer months and, while sectors with partial beam blockage were rather limited, we did find some instances where rainfall and partial blockage coincided, particularly to the south-southeast of the radar and, to a lesser extent, to the north-northwest (see Figs 6-9 and Fig 2; especially, compare Fig 7(a-d) and Fig 2b for the situation at 0.5^0 elev.). We can infer from the texture of the Fig 7(a-c) images, and from long-term accumulations (not shown here), that the echoes near and to the east of the radar were primarily precipitation artifacts caused by clutter contamination, whereas the smoother echoes farther from the radar to the north and south appear to have been "real" precipitation. Interestingly, we observe that the R(Kdp) fields (Fig 7d) tend to be quite consistent with the R(Zh) fields (Figs 7a-c) in areas where we believe precip to be real, but the R(Kdp) fields are much "cleaner" nearer to the radar, where they were much less affected by clutter contamination.

- For the Colorado cases, we feel we were generally successful in finding good-quality verification fields (i.e. "Stage IV" data, prepared at NCEP from products originally prepared at CBRFC). Fig. 10a depicts 6-hour Stage IV accumulation for the period 07/20/2006, 18-24z, while 10b depicts the analogous $R(Z_0)$ field from our S-Pol processing system after translation to the HRAP grid.

- In the statistical analysis of the various accumulation methodologies vs. Stage-IV verification that follows, we used subjective quality control techniques to first remove clutter contamination from the various R(Zh) fields, wherever possible. Also, only HRAP grid points that were within the original coverage area of the S-Pol radar were included.

Statistical Analysis

For the reasons cited above, the following statistical analysis applies only to our COLORADO cases.

For the June, July and August, 2006 dates processed, we compared hourly accumulations determined from each of the three methodologies $R(Z_0)$, $R(Z_{90})$ and $R(K_{dp})$ against the Stage IV verification data on the HRAP (~4km x 4 km) grid under various blockage

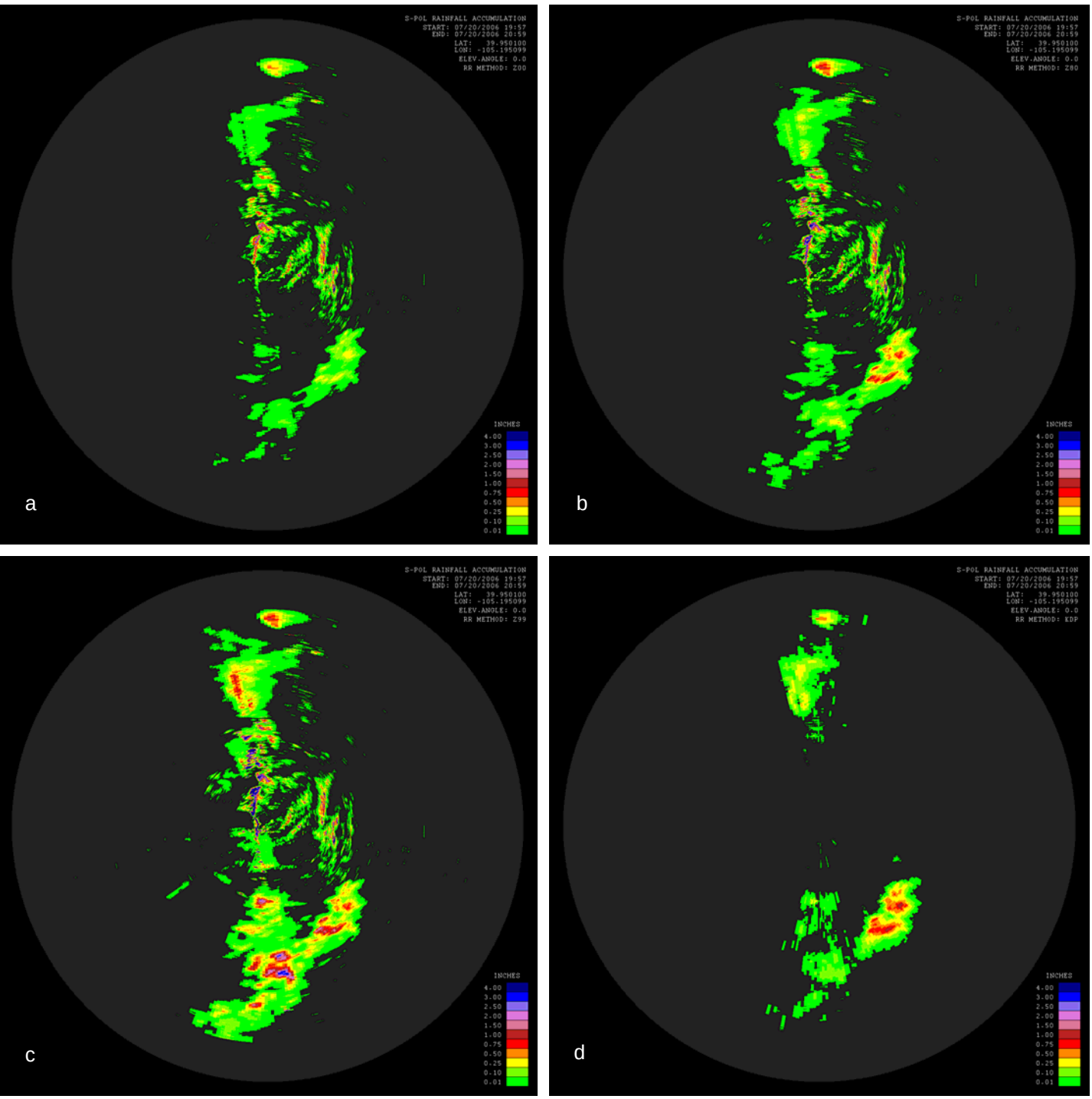

Figure 6. 1-hour accumulations at 0.0^0 for **Colorado** S-Pol site on 07/20/2006, 20-21z : a) $R(Z_0)$; b) $(R(Z_{80})$; c) $R(Z_{99})$; and d) $R(K_{dp})$

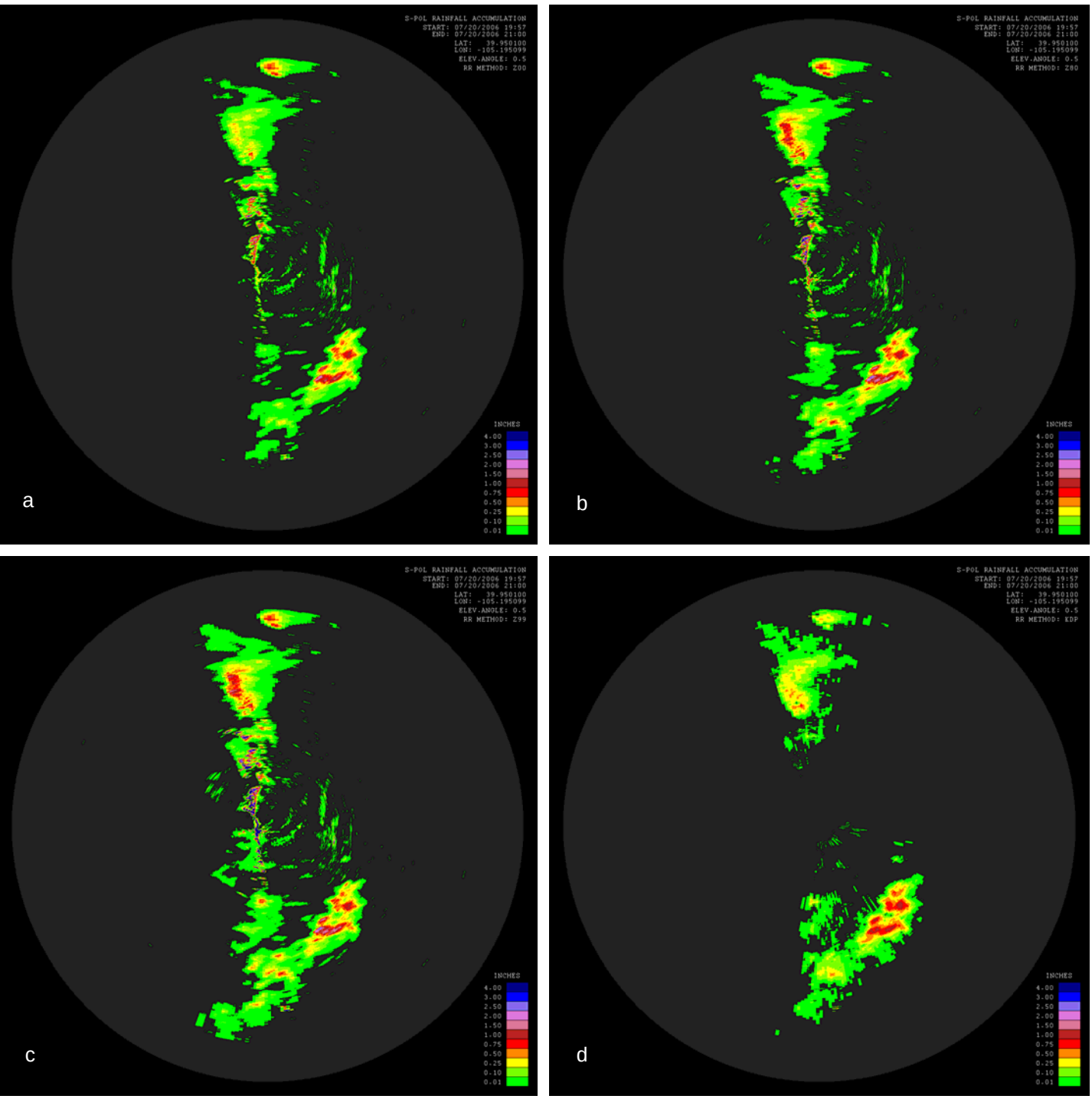

Figure 7. Same as Fig 6 except at 0.5^0

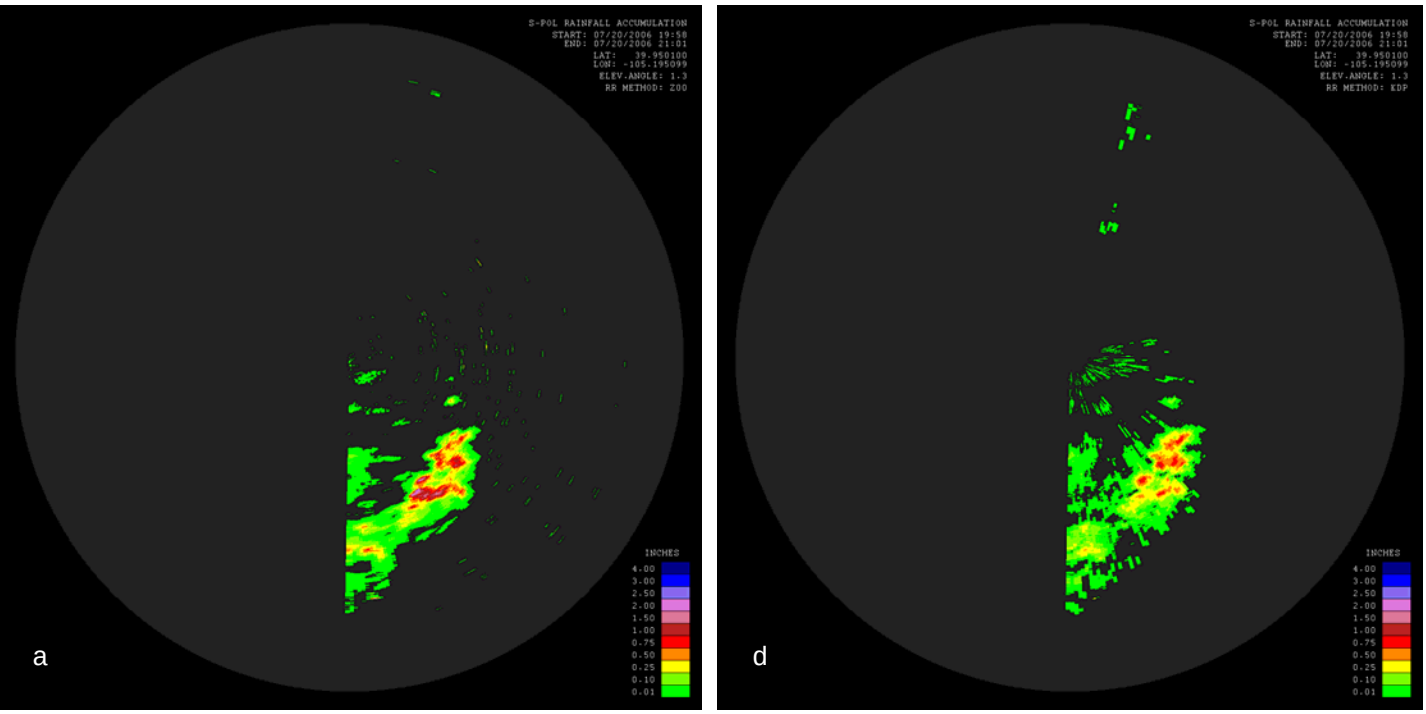

Figure 8. Same as Fig 6 except at 1.3^0. (Note that only Figs a) $R(Z_0)$ and d) R(Kdp) are shown, as b) $R(Z_{80})$ and c) $R(Z_{99})$ are essentially the same here as $R(Z_0)$)

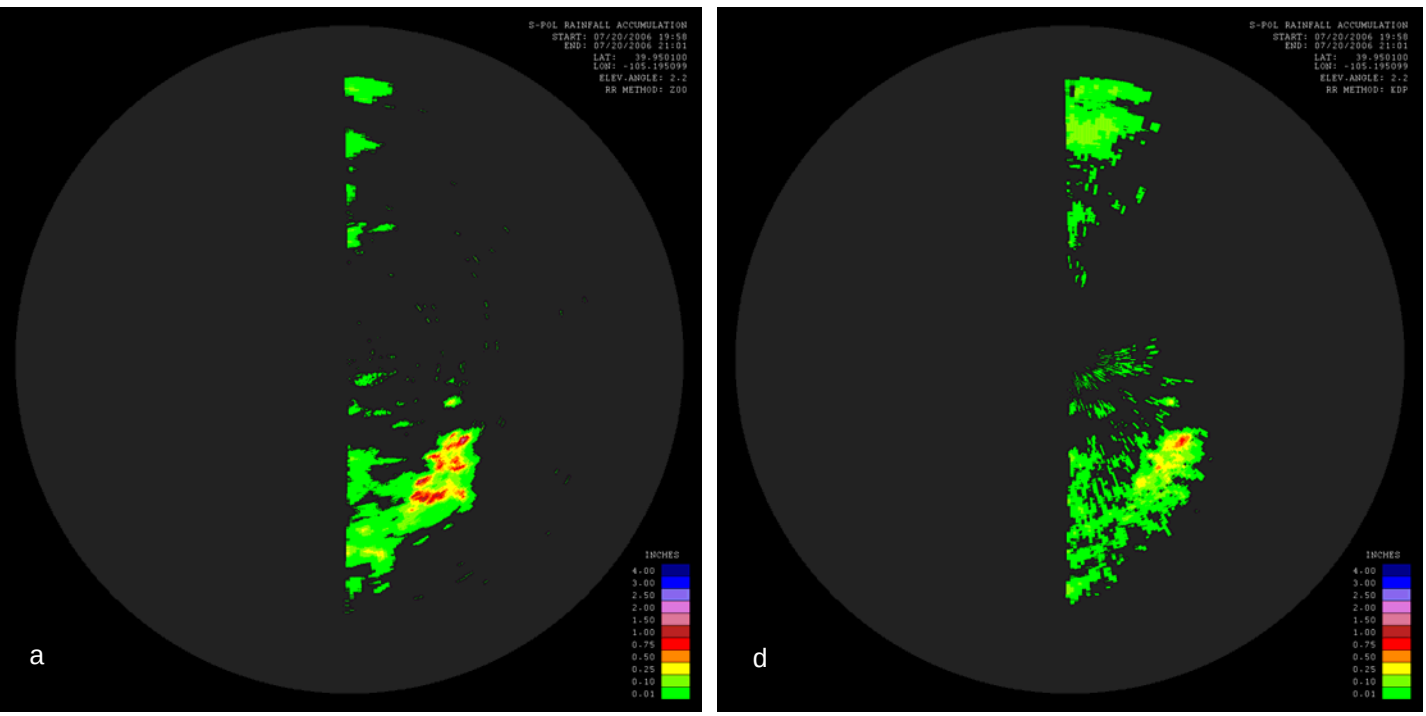

Figure 9. Same as Fig 8 except at 2.2^0

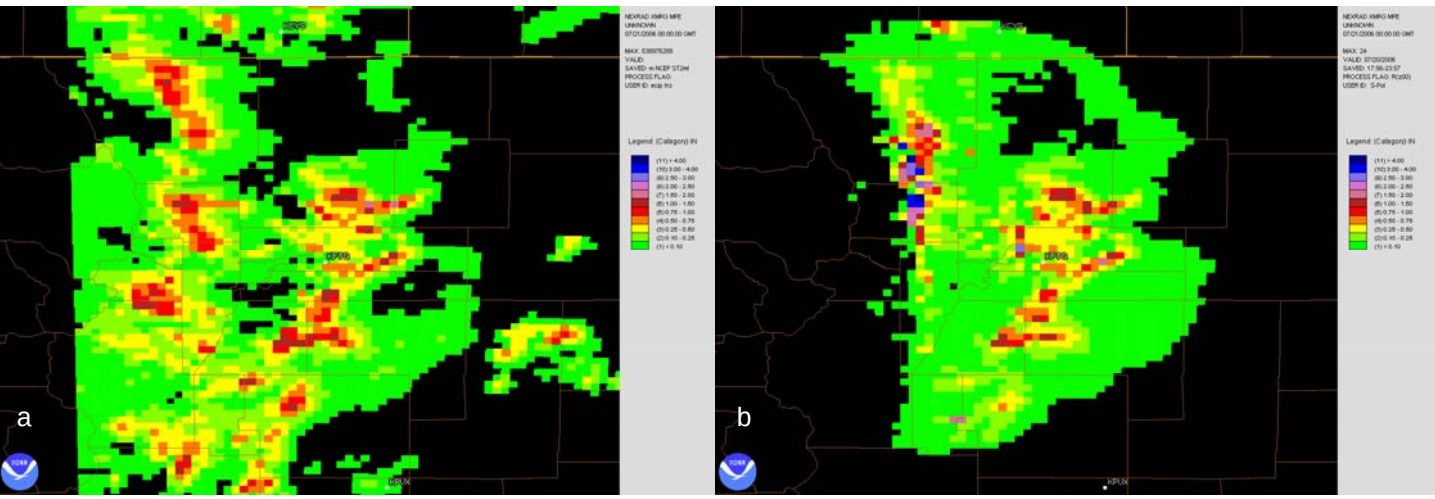

Figure 10. 6-hour accumulations for **Colorado** on 07/20/2006, 18-24z: a) Verification data, from NCEP Stage IV radar-gauge product, on 4-km (HRAP) grid; b) ($R(Z_0)$ at 0.5^0, from S-Pol site, translated to HRAP grid.

conditions. The criterion for including a given grid box for a given hour in the statistical analysis was that one among the measures from S-pol or Stage IV had to be non-zero. All QPE values were determined from elevation 0.5^0; mean-field bias corrections were *not* applied; **51,290** boxes, in total, over **161** hours, were included in the sample.

Figures 11-13 illustrate our analysis methodology for an indicative time period – i.e. one-hour accumulation ending 07/04/2006, 00Z. Fig 11 (a,b,c) depict the accumulations from $R(Z_0)$; $R(Z_{90})$; $R(K_{dp})$ at 0.5^0 on the S-Pol (az/ran) grid; Fig 12 (a,b,c) depict the analogous accumulations after translation to the ~4km x 4 km HRAP grid; Fig 12 (d) shows the verification (Stage IV) product on the same HRAP grid; Fig 13 shows the beam blockage (by percentage) at 0.5^0, also after translation to the HRAP grid.

Figure 14 provides a statistical breakdown, in the form of bar diagrams, of all the June-August, 2006 one-hour accumulations generated via the three QPE methodologies against the hourly Stage IV verification field, stratified by percentage of beam blockage into four groupings: 0-25%; 25-50%; 50-75%; and 75-99%. Within this dataset, R(Zh) correction did not exceed that for 90% blockage – i.e. 10x power enhancement. Each percentage-grouping had a fair number of samples (at least 4,700). Figs 14 (a,b,c) depict the fields Radar/Stage IV Ratio; Correlation Coefficient; and Error Standard Deviation, respectively.

In Fig 14a, it is seen that the precipitation estimates from all the methodologies in all blockage categories were less than the Stage IV verification fields – i.e. all ratios < 1.0. In all percentile categories except 0-25%, $R(K_{dp})$ yields a higher estimate (closer to the verification) than $R(Z_0)$, particularly when blockage exceeds 50%. In all categories, though, the enhanced R(Zh) field (i.e. $R(Z_{90})$) yields the closest estimate to the verification.

In Fig 14b, it is seen that in all blockage percentiles, $R(Z_0)$ yields a higher correlation with the verification field than $R(K_{dp})$, with the gap being similar in all blockage categories. This is not what might be expected from the theoretical behavior of $R(K_{dp})$ – i.e. if truly unaffected by the presence of partial beam blockage, its relative performance vs. $R(Z_0)$ should improve as blockage percentage increases. When traditional R(Zh) is enhanced to compensate for beam blockage (i.e. $R(Z_{90})$), the correlation against the verification field is comparable, overall, to that of unenhanced R(Zh) – with both 'outperforming' $R(K_{dp})$. This finding suggests that, within any one local sector affected by terrain blockage within some limited percentage interval, the time history of precipitation can be reliably retrieved from uncorrected Zh, even though the blockage introduces a low bias in the resulting rainfall estimates.

In Fig 14c, it is seen that the Error Standard Deviation is slightly higher, overall, for $R(K_{dp})$ than $R(Z_0)$, though in conditions of blockage exceeding 50% there is a slight tendency toward the opposite. Overall, though, it is the $R(Z_{90})$ field that yields the lowest error standard deviation, particularly when blockage exceeds 50%.

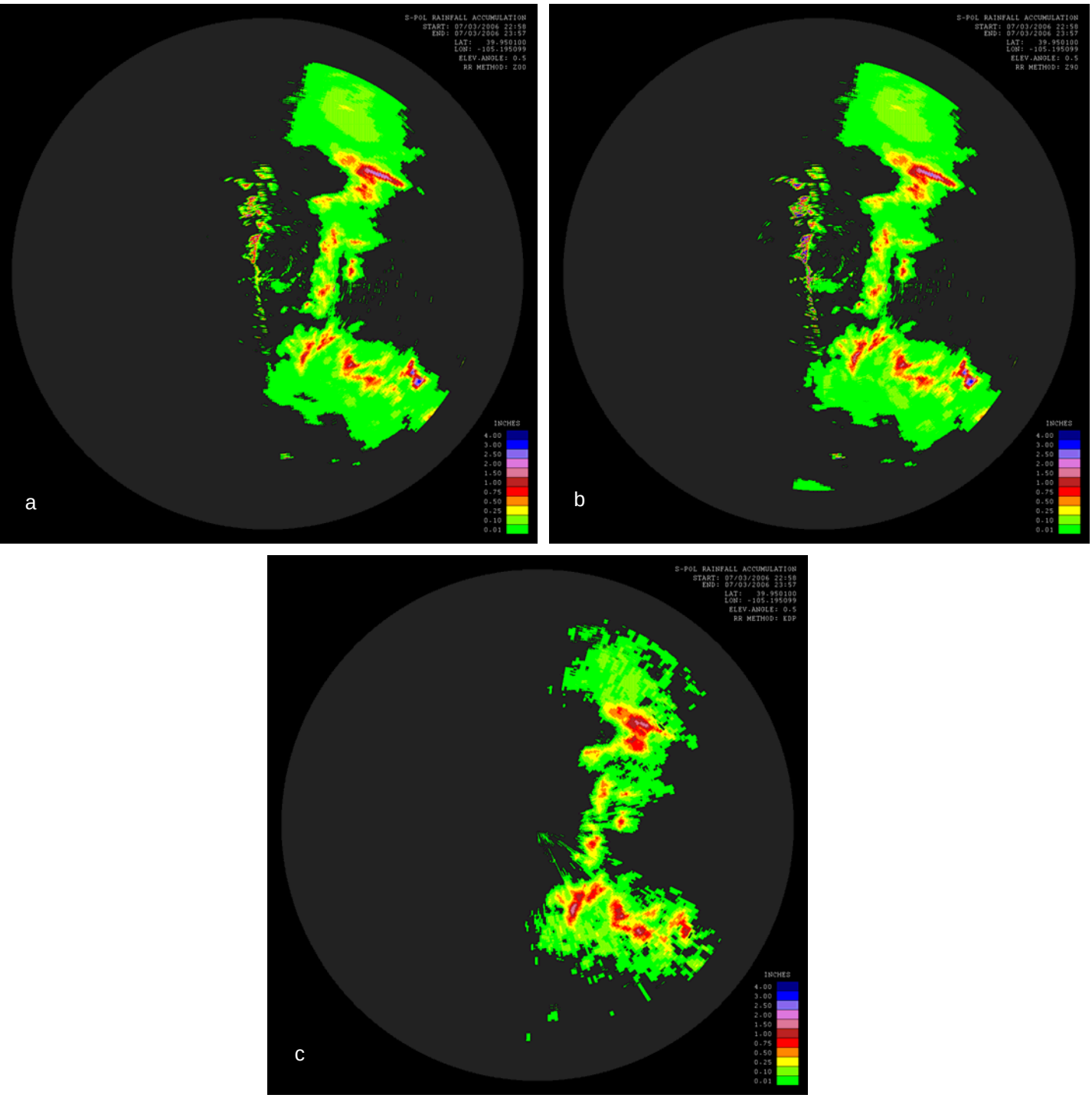

Figure 11. 1-hour accumulations at 0.5^0 for **Colorado** on polar grid centered at S-Pol site, ending 07/04/2006, 00z: a) $R(Z_0)$; b) $R(Z_{90})$; and c) $R(K_{dp})$.

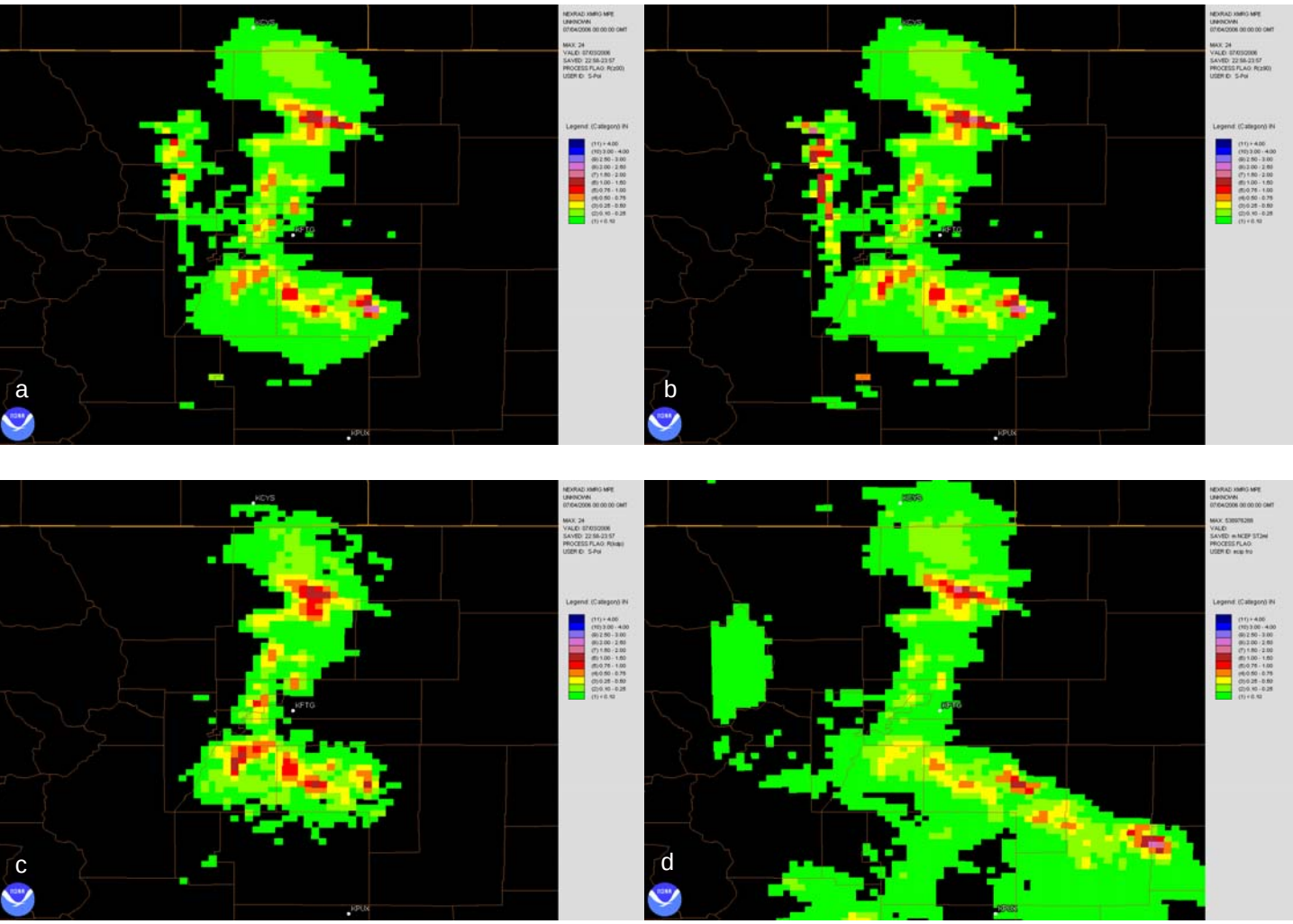

Figure 12. 1-hour accumulations at 0.5^0 for **Colorado** on ~4x4 km^2 HRAP grid centered approx. at S-Pol site, ending 07/04/2006, 00z (i.e. same as Fig 12 after translation to HRAP grid): a) $R(Z_0)$; b) $R(Z_{90})$; c) $R(K_{dp})$; also d) Stage IV (verification).

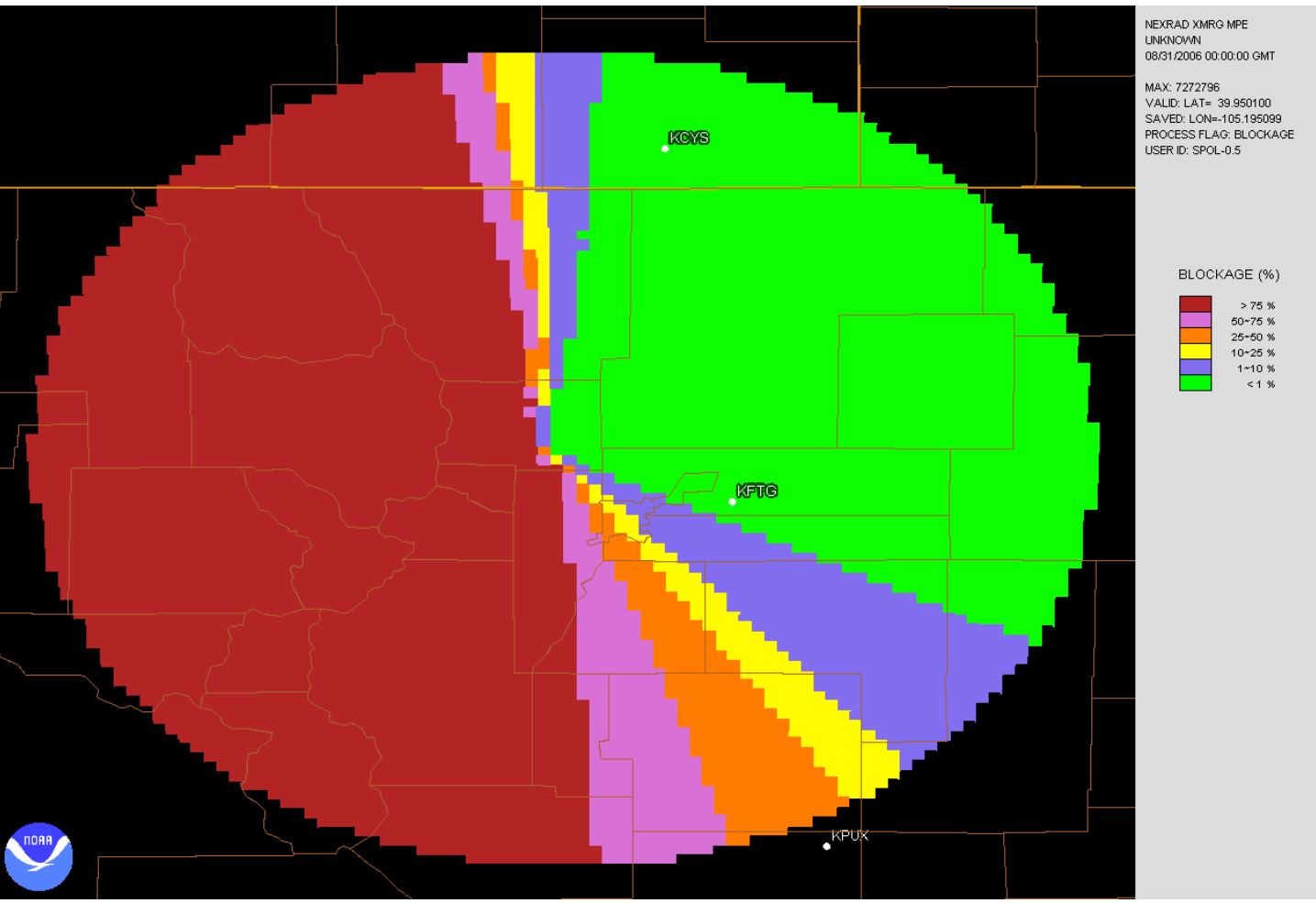

Figure 13. Beam blockage at 0.5^0 for **Colorado** on ~4x4 km^2 HRAP grid centered approx. at S-Pol site (analogous to Fig 2b).

In looking at each QPE measure, individually, over the range of blockage, the performance of each is seen to drop off in all statistical categories as blockage increases, particularly when blockage exceeds 50% Overall, the relative drop-off in performance for $R(K_{dp})$ between the 25-50% and 50-75% groupings is not as severe as that for $R(Z_0)$, but is more severe than that for $R(Z_{90})$. It is noted that there is some improvement in the 75-99% range for all statistical measures in the Error Standard Deviation field.

Figure 15 (a-d) is analogous to Fig 12 (a-d) in that it shows accumulations from the various QPE methodologies at 0.5^0, as well as the verification field, on the HRAP grid, though here for the sum of all available accumulations throughout the experimental period June-August, 2006.

Figure 16 (a-c) provides similar statistical breakdowns to Fig 14 (a-c), though here for the summed QPEs depicted in Fig. 15. Thus the verification statistics indicate the reliability of the various radar algorithms in modeling long-term spatial variations in rainfall. A total of **2,065** boxes were included in the sample. Overall, these results are rather similar, per statistical category, to the analogous measures for the hourly analysis, although some relative improvement is seen in the performance of $R(K_{dp})$ against $R(Z_0)$ for Correlation Coefficient and Error Standard Deviation. However, altogether, the enhanced R(Zh) field (i.e. $R(Z_{90})$) yields the 'best' performance (of the three compared) for each statistical measure – i.e. highest Radar/Stage IV Ratio; highest Correlation Coefficient; lowest Error Standard Deviation.

Preliminary Findings

Our primary findings for the cases analysed to date (i.e. Colorado, June-August 2006) are that, even during primarily summer convective precipitation, rainfall estimates from the dual polar, the specific differential phase algorithm do not, or just slightly, outperform estimates from the traditional, Z-R relationship enhanced to compensate for partial beam blockage ($R(Z_0)$). Indeed, $R(K_{dp})$ appears to exhibit a low bias relative to gauge-radar based verification as blockage increases above 50%. Overall, rainfall derived from the Z-R relationship but enhanced to compensate for blockage up to 99% (with correction capped at that for the 90% blockage level) yields the best performance among all three QPE measures compared in this study. This finding is consistent with that of Lang et al. (2009), who reported that a terrain-blockage correction to Zh yielded good-quality rainfall estimates even in sectors with serious blockage.

It should be noted, though, that since the Stage IV verification field is prepared from a combination of rain gauge and WSR-88D precipitation fields derived, likewise, from the horizontal Z-R relationship, there might be an inherent bias in our methodology in favor of the $R(Z_0)$ and $R(Z_{90})$ methodologies over that of $R(K_{dp})$.

Task 2: Collection of snowfall reports over Indiana and Illinois for future development of a dual-polarization radar snowfall algorithm

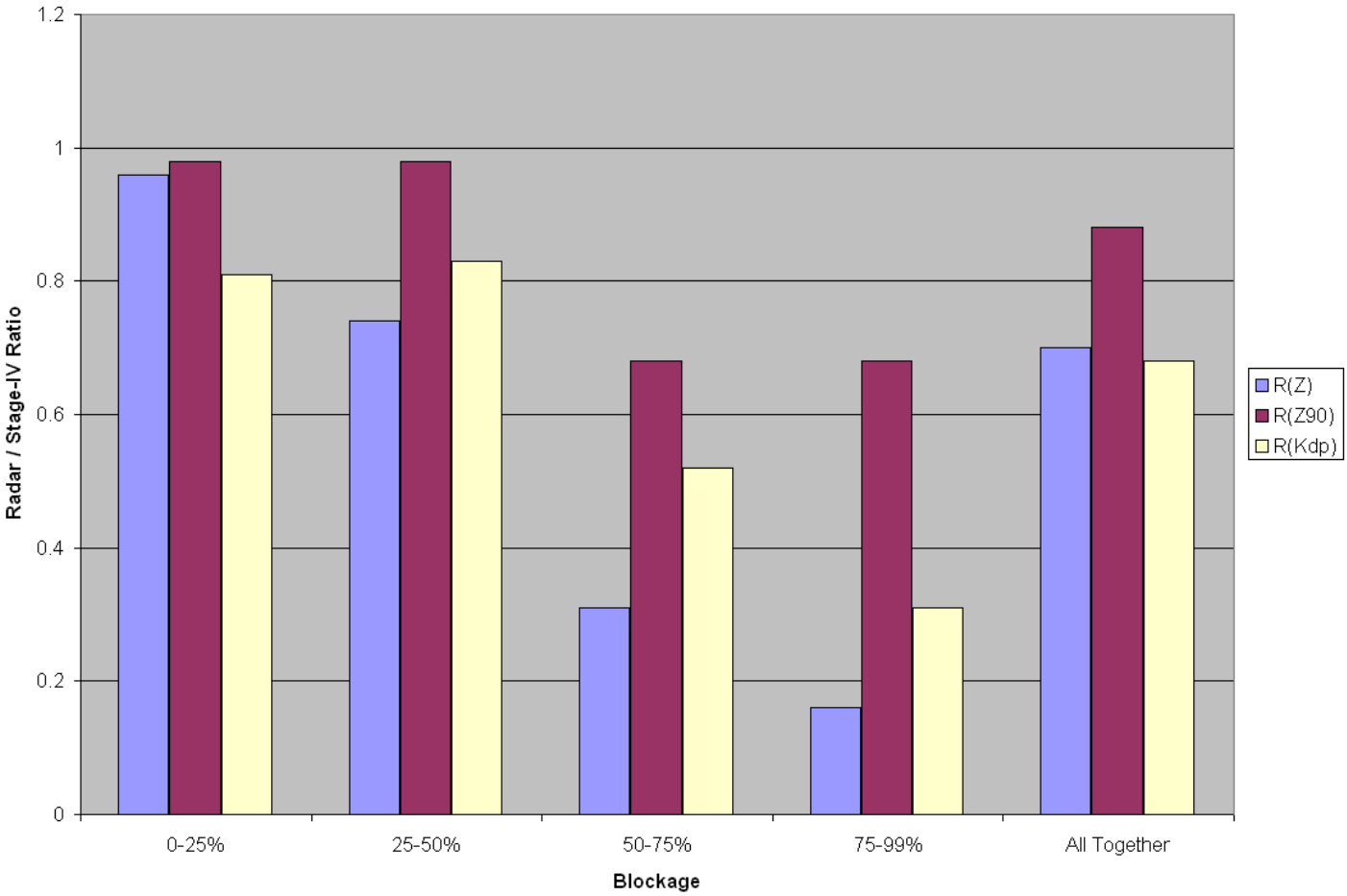

Figure 14a. Statistical comparison **(Radar/Stage IV Ratio)** of 1-hour accumulations by different methodologies (blue: $R(Z_0)$; red: $R(Z_{90})$; yellow: $R(K_{dp})$) vs. Stage IV verification, for all June, July & August 2006 **Colorado** cases (at 0.5^0) with non-zero accumulation. Stratified by blockage percentage (0-25%: 29,520 HRAP grid boxes; 25-50%: 4,702 boxes; 50-75%: 7,838 boxes; 75-99%: 9,230 boxes) and all cases considered together (51,290 boxes).

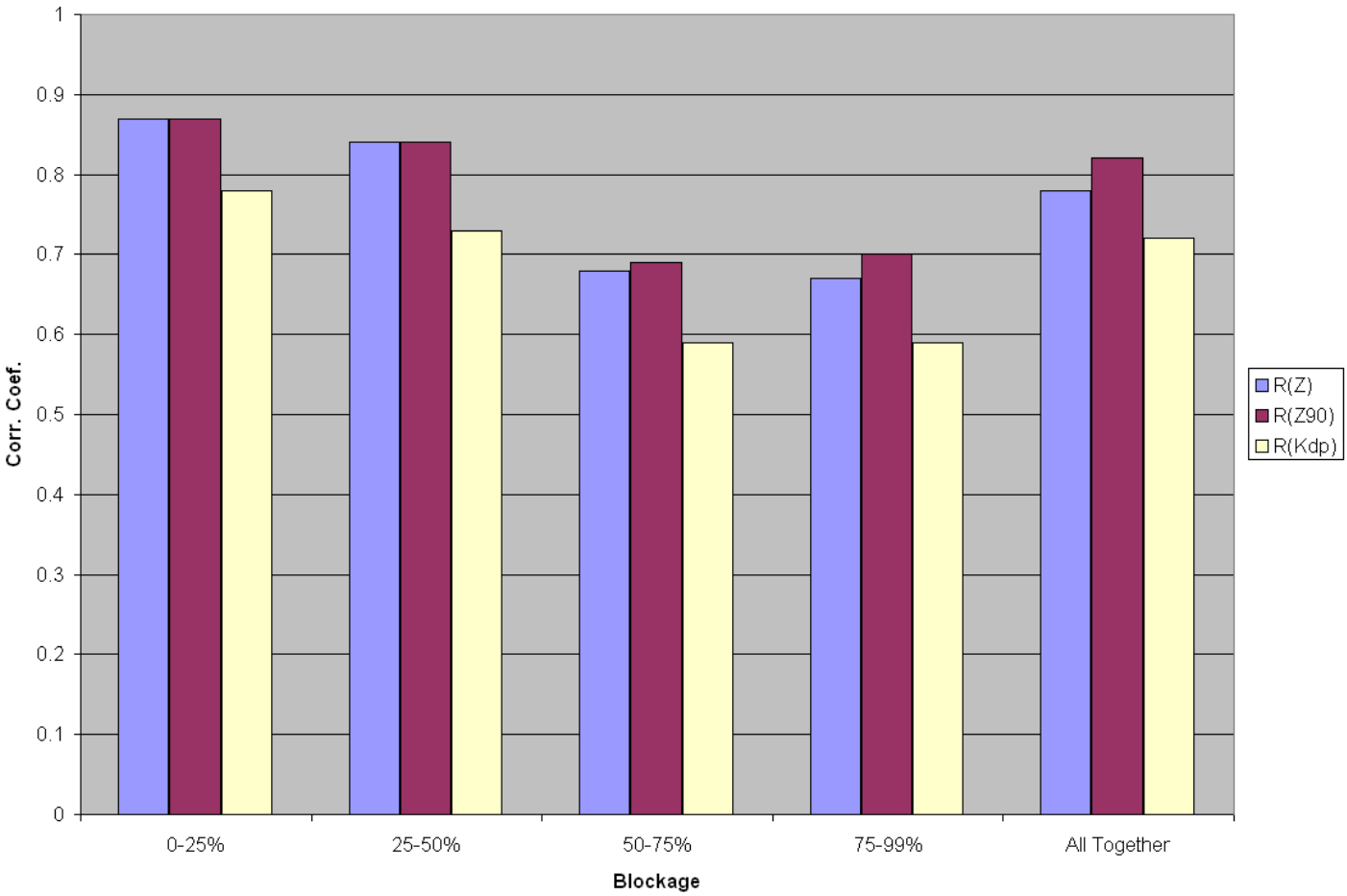

Figure 14b. Same as Fig. 15a but for **Correlation Coefficient**.

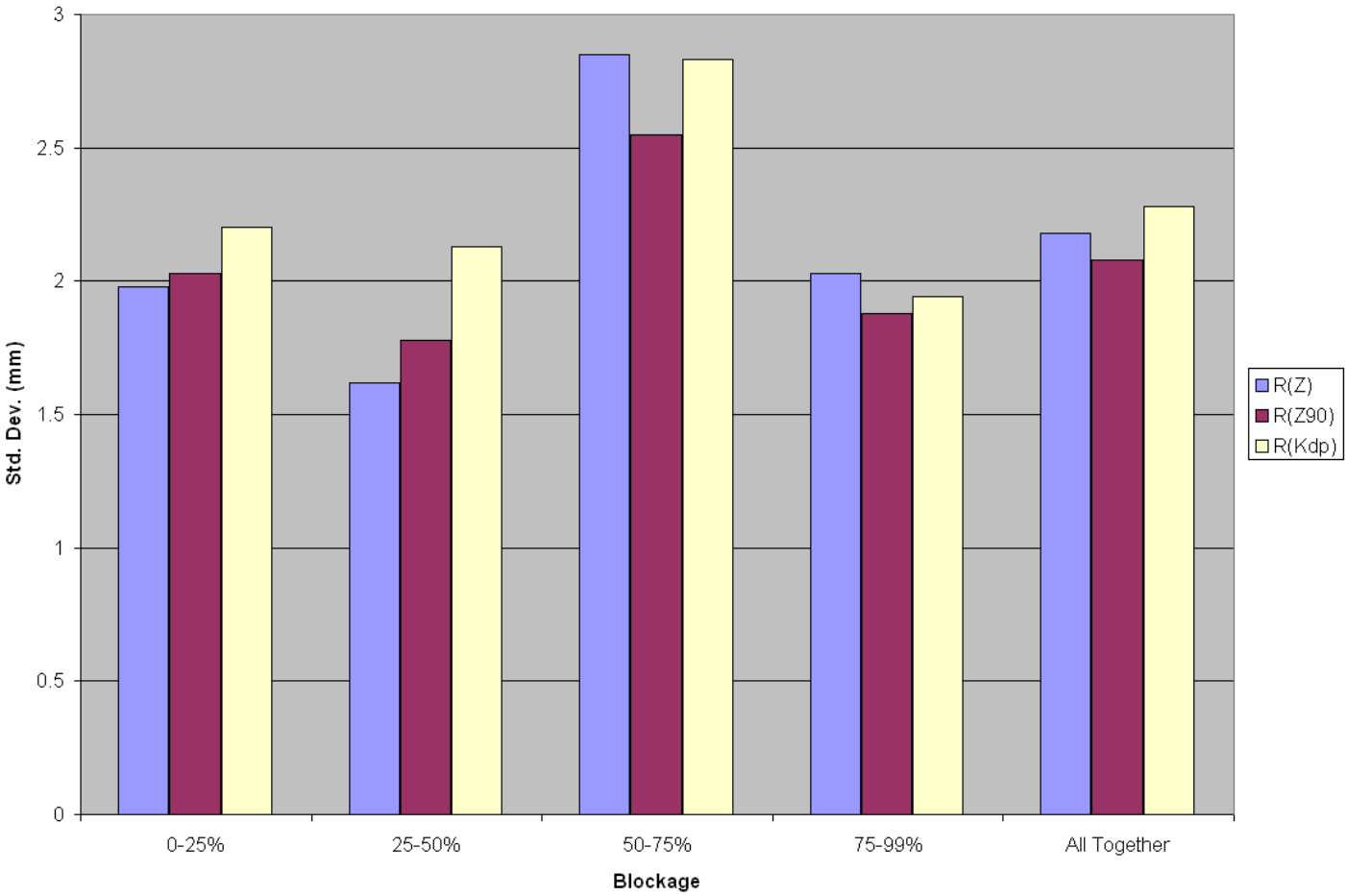

Figure 14c. Same as Fig. 15a but for **Error Standard Deviation**.

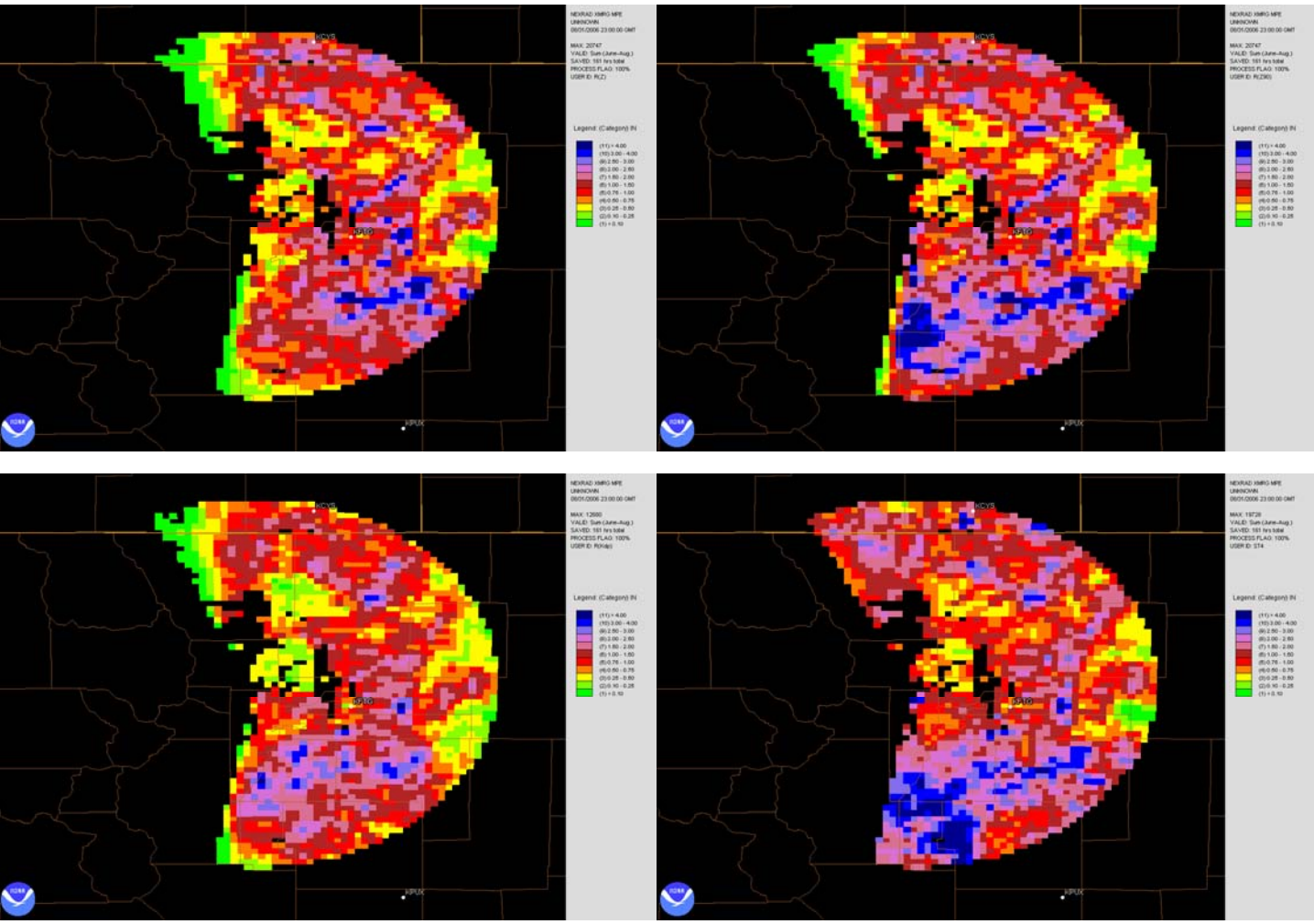

Figure 15. Long-term accumulation during summer season (161 days during June, July, August 2006) at 0.5^0 for **Colorado** on ~4x4 km^2 HRAP grid centered approx. at S-Pol site, after translation to HRAP grid: a) $R(Z_0)$; b) $R(Z_{90})$; c) $R(K_{dp})$; also d) Stage IV (verification). Note: gridpoints determined (by subjective QC analysis) to be substantially contaminated by clutter have been removed (appear as background black).

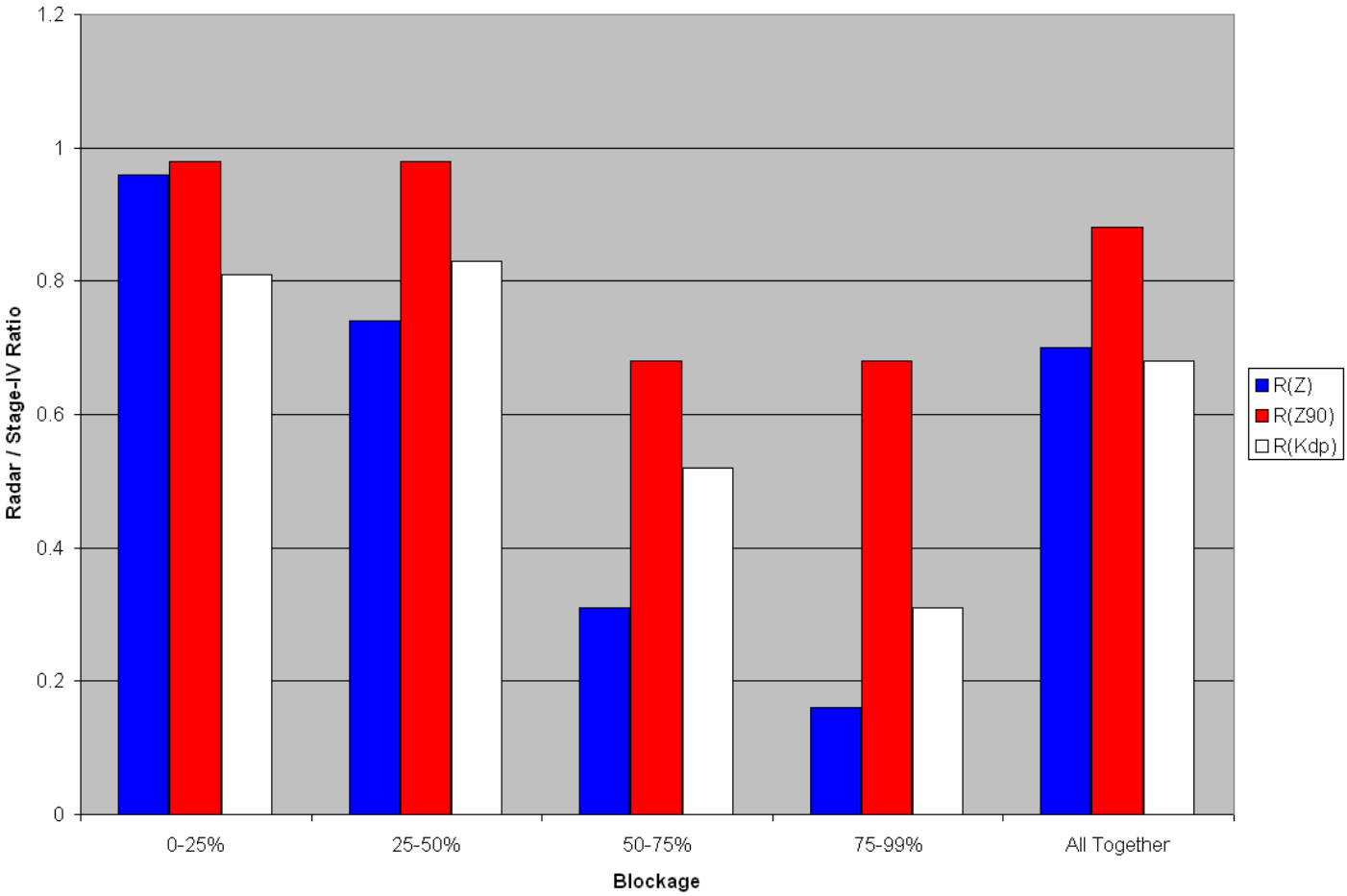

Figure 16a. Statistical comparison **(Radar/Stage IV Ratio)** of summed accumulations (i.e. spatial correlation) by different methodologies (blue: $R(Z_0)$; red: $R(Z_{90})$; white: $R(K_{dp})$) vs. Stage IV verification, for all June, July & August 2006 **Colorado** cases (at 0.5^0). Stratified by blockage percentage (0-25%: 1,464 HRAP grid boxes; 25-50%: 148 boxes; 50-75%: 196 boxes; 75-99%: 257 boxes), and all cases considered together (2,065 boxes). The overall result ('All together' category) indicates that $R(Z_{90})$ is best at replicating the long-term precipitation distribution over the radar umbrella.

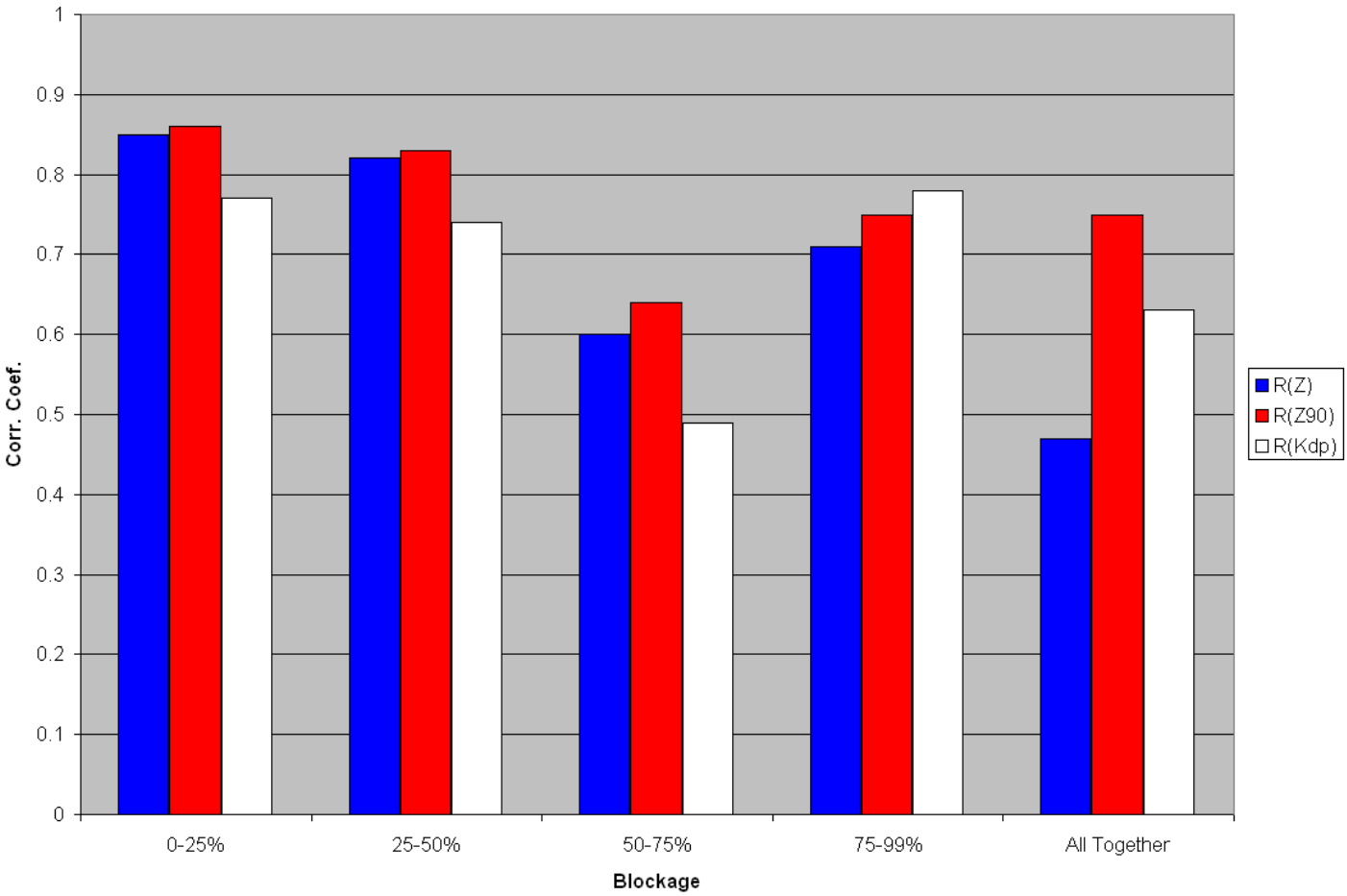

Figure 16b. Same as Fig. 16a but for **Correlation Coefficient**.

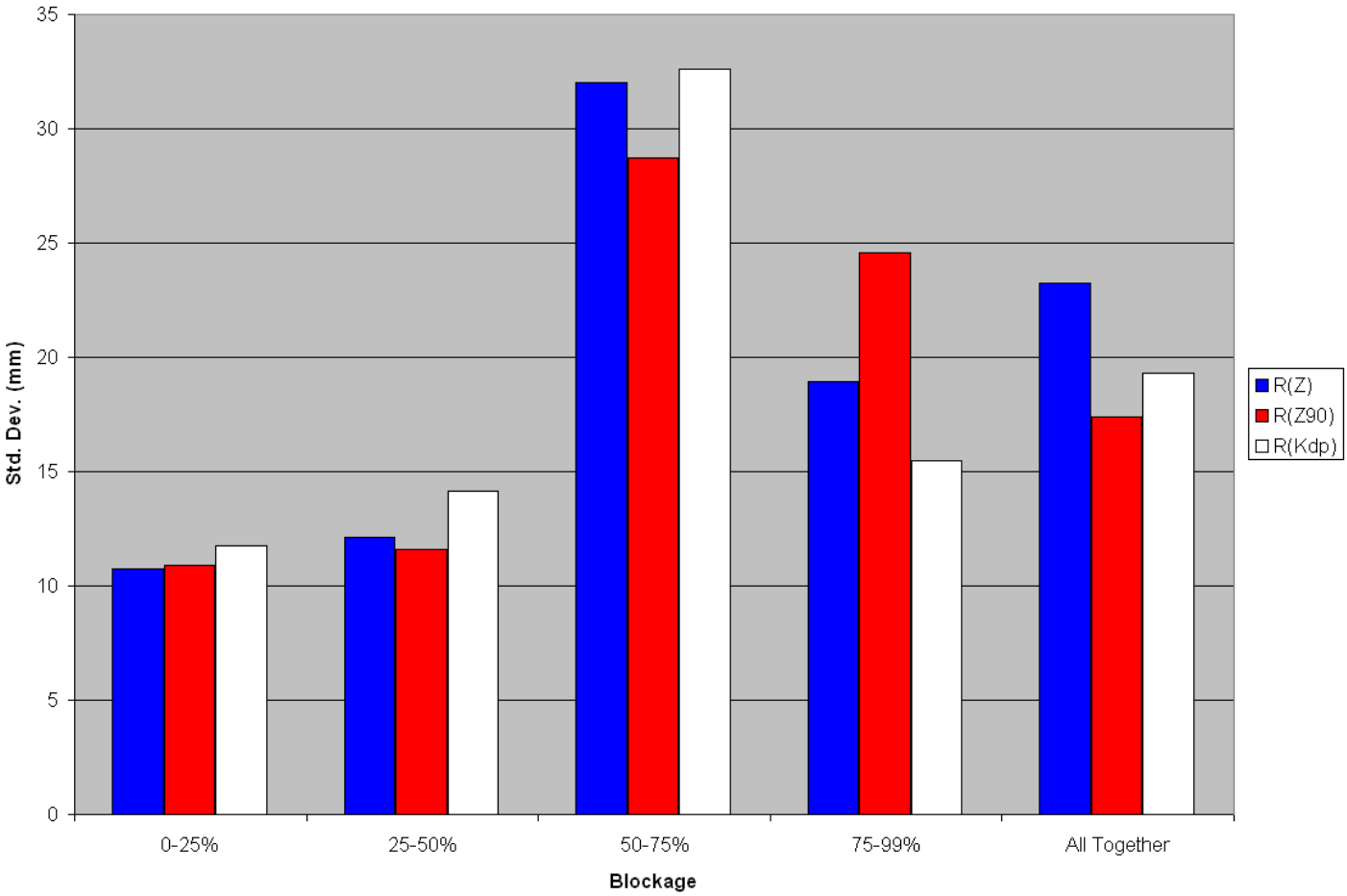

Figure 16c. Same as Fig. 16a but for **Error Standard Deviation**.

Task 2: Collection of snowfall reports over Indiana and Illinois for future development of a dual-polarization radar snowfall algorithm

A long-term goal shared by ROC, NSSL, and OHD is the creation of a dual-polarization snowfall estimation algorithm. Creation of such an algorithm is complicated by the relative scarcity of dual-pol observations during snow events in the Oklahoma area. Currently, NSSL and ROC staff are seeking a collaborative agreement with faculty of the Valparaiso (Indiana) University meteorology department, who maintain a C-band dual-polarization radar and archive its observations. Some form of reference snow observations are necessary for development and calibration of the algorithm. After consultation with ROC and NSSL staff (Daniel Berkowitz and Alexander Ryzhkov) we collected an initial set of snowfall observations from northern Indiana and northern Illinois for several events during the period December 2007 to March 2008. This period featured several light-to-moderate snowfalls (up to ~8" in the heaviest event), with both dry snow events and wet snow/mixed-precipitation events.

It is well-known that proposed automated measurement of snow is complicated by drifting effects, and measurement of snow water equivalent by gauge undercatch (Landolt and Rasmussen 2007; Chagnon 2006; Doesken and McKee 1999). At present, official snowfall observations must still be collected manually (NWS Office of Operational Systems, personal communication). Moreover, relatively few hourly observing sites are staffed to measure snow at less than 24 h intervals.

We collected and when necessary interpreted available daily and sub-daily reports from ASOS, AWOS, and cooperative observer sites in the Community Collaborative Rain Hail & Snow (CoCoRaHS) network. All reports were put into a standardized text format including reporting time in UTC and station latitude-longitude. The source and interpretation methods are described below. The data collection region is enclosed by the white arc in Fig. 17.

ASOS-based snowfall dataset:

This dataset consists of formatted observations decoded from METAR reports, by the NWS Meteorological Development Laboratory (MDL). The dataset contains text information on site name, latitude-longitude, reporting time, temperature, dew point, present weather, and snowfall over 6-h intervals. When necessary, the snowfall was estimated from reported snow depth. For some sites in some cases, 1-h and 3-h snowfall to the nearest inch was available. Note that the present weather variable includes indications of light, moderate, or heavy snowfall (-SN, SN, and +SN), which are potentially useful for identifying local heavy snow bands. Our final dataset includes a binary indicator of snow when it was reported, and heavy snow.

We concentrated on data from four ASOS sites within 120 km of the town of Valparaiso that report snowfall and/or snow depth at 6-h intervals or less. Two sites (Chicago O'Hare and Midway Airports) reported snow depth at 6-h and some sometimes shorter intervals; these were interpreted as 6-h snowfall. Two others (South Bend and North

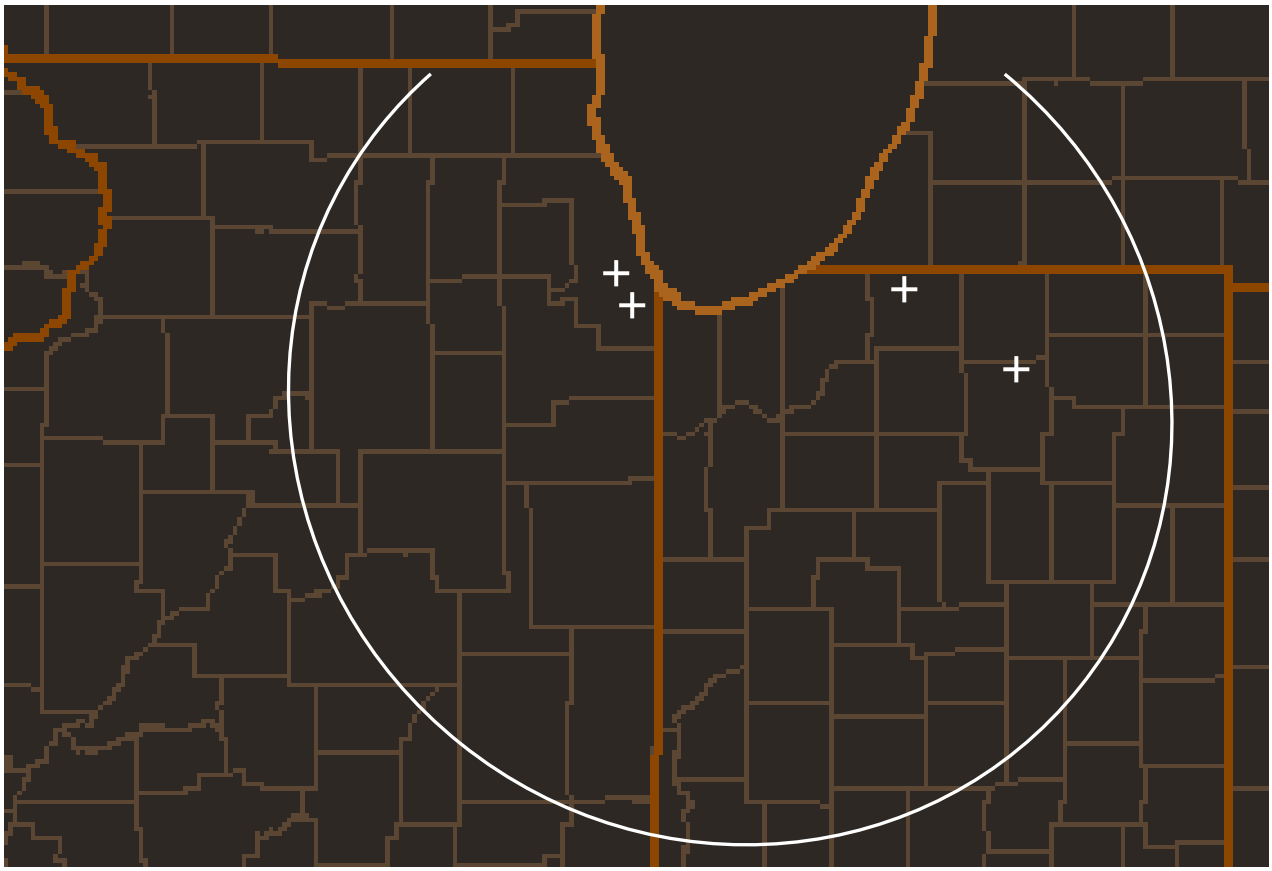

Figure 17.Portions of Indiana and Illinois from which ASOS and CoCoRaHS observations were collected. Crosses indicate locations of ASOS sites reporting subdaily snowfall.

Webster IN) reported 6-h snowfall to the nearest 0.1 inch. These sites are indicated by crosses in Fig. 17.

ASOS and AWOS-based present weather reports, including snow occurrence:

This dataset was collected from NCDC archives, and includes reports of sensible weather and for some points, precipitation type and liquid amount reports from 86 sites in Indiana and Illinois (some beyond the Valparaiso radar umbrella). Of potential interest are data from eleven sites that reported present weather, including rain and snow conditions and snowfall intensity (numerical codes 70-71, 72-73, and 74-75 for light, moderate, and heavy). These include the four ASOS sites that also reported snowfall. Our final dataset includes a binary indicator of snow when it was reported, and heavy snow.

The ASOS and AWOS reports include wind, temperature and dew point reports.

CoCoRaHS dataset:

This dataset contains reports of daily snowfall and liquid precipitation at morning reporting times for 339 sites (CoCoRaHS 2007, 2008). There were a total of 1674 individual reports, since not all sites reported on all days.. Daily report records include date, reporting time, site latitude and longitude, 24-h total snowfall and its liquid equivalent, or total liquid for mixed precipitation events. When narrative reports with snow duration were included, the ending time and duration of the snow portion of the event were coded into separate fields. The daily snow amounts correspond to the deepest known snowfall during the daily period, whether or not the new snowpack was subsequently affected by melting or compression.

Though CoCoRaHS reports are listed in local time, our output has been adjusted to UTC, accounting for those Indiana counties that are located in the Central Time Zone.

General output format:

All data have been stored in a standard text format with 228-byte line records. A header line with abbreviated text descriptions, delimited by colons (:) appears in each data file. The fields are as follows. A blank indicates no report.

Nominal report date-time in UTC (yyyymmddhh)
Site identifier
Reporting site type (WFO, ASOS, COCO)
Site decimal latitude and west longitude
Actual report time (hhmm)
Temperature, dew point (ºF)
Present weather (METAR text or coded numeric)
Visibility (miles)
Wind direction and speed (knots)
Precipitation amount (.01 inches, .005 for trace) (1, 3, 6, 24 for duration)

SND for snow depth in inches when reported
SNF for snow occurring at time of ob (blank or 1)
HVY for report of heavy snowfall at time of ob (blank or 1)
Snowfall amounts for 1, 3, 6 hours (inches) if reported or derived; .01 for trace
Snowfall of other duration, inches
Duration of last snowfall report, hours

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Appendix: S-pol cases processed to date

- OREGON S-Pol cases:

  - OREGON: to date, we have generated QPE estimates for nearly 450 periods (mostly 1-hour accums of $R(Z_0)$ at 0.5^0 only). For the following date/times, we generated some or all of the rainfall fields ($R(Z_0)$; ($R(Z_{80})$; $R(Z_{90})$; $R(Z_{99})$; and $R(K_{dp})$) at each of the elevations: $\{0.5^0; 1.5^0; 2.4^0\}$:
    - 12/13/2001 ~18z to 24z (six individual 1-hour periods); (see Figs 3, 4 & 5);
    - (same date) ~20z to 23z (one 3-hour period); and
    - (same date) ~19z to 24z (one 5-hour period)
    - (During the nearly month-long interval 11/27/2001 to 12/22/2001, we generated 1-hour accumulations for over 400 individual hours, though for $R(Z_0)$ at 0.5^0 only)

- COLORADO S-Pol cases:

  - COLORADO: to date, we have generated QPE estimates for some or all of the rainfall fields ($R(Z_0)$; ($R(Z_{80})$; $R(Z_{90})$; $R(Z_{99})$; and $R(K_{dp})$) at some or all of the elevations $\{0.0^0; 0.5^0; 1.3^0; 2.2^0\}$ for the following dates/periods:
    - 07/03/2006 ~22z to 23z (1-hr) and ~19z to 24z (5-hrs);
    - 07/20/2006 ~20z to 21z (1-hr) and ~18z to 24z (6-hrs); (see Figs 6, 7, 8 & 9)
    - 08/01/2006 ~03z to 04z (1-hr) and ~02z to 08z (6-hrs);
    - 08/06/2006 ~23z to 24z (1-hr) (0.5^0 only)

- Verification datasets:
  - OREGON (NCEP Stage II radar-gauge product, 4-km grids):
    - 12/13/2001 18z to 24z (6-hrs) (*note: upon further evaluation, we determined that these verification fields were of inadequate quality to use in our analysis*);
  - COLORADO (NCEP Stage IV radar-gauge product, 4-km grids):
    - 07/20/2006 18z to 24z (6-hrs) (see Fig. 10a; compare to 10b);
    - 08/06/2006 23z to 24z (1-hr);
    - 08/06/2006 18z to 24z (6-hrs);
    - 08/07/2006 18z to 24z (6-hrs)