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Creating a Seamless Map of Gage-Adjusted Radar Rainfall Estimates for the State of Florida

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Abstract

Rainfall distributions from rain gages are typically estimated by assuming a spatial geometry tied to point rain gage observations using, for example, Thiessen polygons, inverse distance squared weighting, or statistical Kriging techniques. Unfortunately, the spatial distributions inferred by these approaches have little connection with how rain actually falls. Since the release of the WSR-88D (NEXRAD) radar in the early 1990s, many hydrologists and engineers have begun using gage-adjusted radar rainfall estimates for hydrologic and water resource modeling.

Over large areas under multiple NEXRAD radar coverages, the quality of radar rainfall estimates can vary significantly from one location to another. Visible discontinuities can develop at the limits of coverage of a single NEXRAD site because of slightly different performance or calibration techniques used at the different radar sites. Using a variety of GIS procedures for this study, these discontinuities were eliminated and locations of ground clutter were suppressed, yielding a seamless map of unadjusted radar rainfall estimates.

These data were adjusted with over 400 rain gages located throughout the state using a modified spatial adjustment technique originally developed by Brandes at the National Severe Storms Lab in the mid-1970s. This approach was able to retain the volumetric rainfall estimates from the gages while maintaining the spatial signature of the rainfall. Use of this technique greatly improves gage-adjusted radar rainfall estimates.

Introduction

Rainfall distributions from rain gages are typically estimated by assuming a spatial geometry tied to point rain gage observations using, for example, Thiessen polygons, inverse distance squared weighting, or statistical Kriging techniques. Unfortunately, the spatial distributions inferred by these approaches have little connection with how rain actually falls. Since the release of the WSR-88D (NEXRAD) radar in the early 1990s, many hydrologists and engineers have begun using gage-adjusted radar rainfall estimates for hydrologic and water resource modeling.

Since each WSR-88D radar measures rainfall out to a distance of 230 km (Fulton et al. 1998), the radar data are mosaiced to create maps of rainfall estimates over large areas, such as the state of Florida. Over large areas under multiple WSR-88D radar coverages, minor performance differences between individual radars can accumulate to create discontinuities in the mosaiced radar field.

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Figure 1 shows the qualitative rainfall estimates over a long-term duration (15 months). At long time integrations, three characteristics become visible: a discontinuity at the location of a change in scan elevation called the hybrid scan discontinuity (the most prevalent is at 11 nm (20 km) from the WSR-88D), a discontinuity at the 230-km limits for each of the WSR-88D radars and isolated locations of ground clutter. Hybrid scan discontinuities are visible at each radar site, but the most prevalent is at the 11 nm (20 km) radial ring around the Jacksonville radar in the northeast corner of the state. The discontinuity at the 230-km limit is visible from the Jacksonville radar as well as from the Key West and the Miami radars, among others.

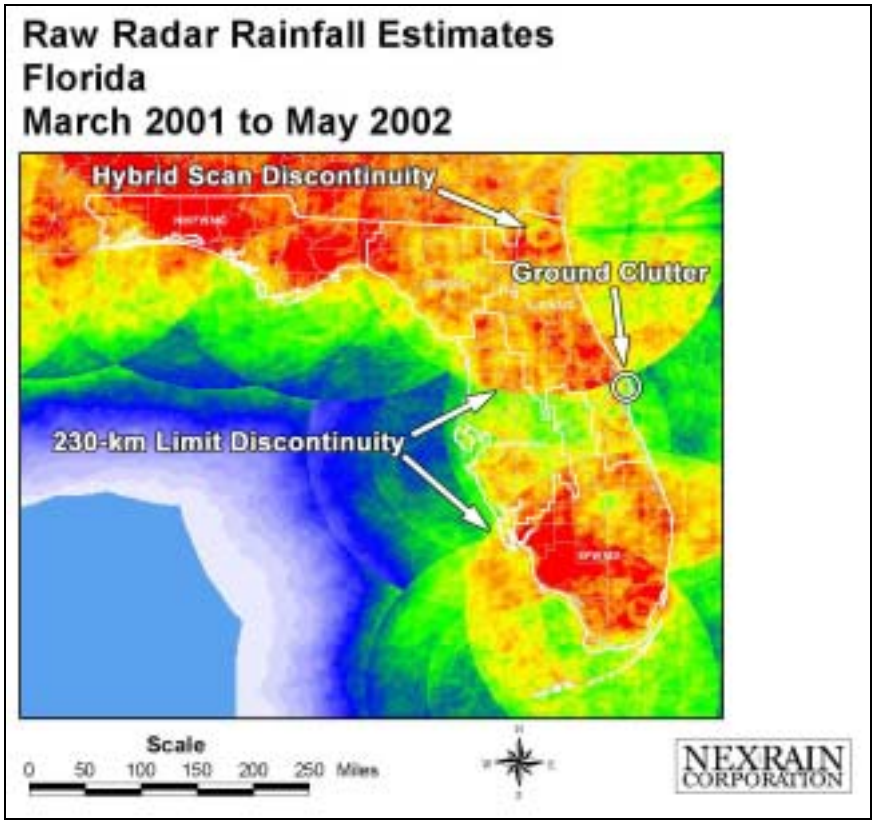

Figure 1: 15-Month Radar Rainfall Accumulation from March 2001 to May 2002.

Note that radar rainfall estimates extend beyond the 230-km limits over the Gulf of Mexico. WSI Corporation, NEXRAIN's radar rainfall provider, extends the rainfall estimation algorithms beyond the 230-km limit in areas that are not covered under the 230-km limits of another radar.

The goal of the procedure was to eliminate the discontinuities that are evident in a mosaiced radar rainfall dataset and to create an adjustment procedure which accurately characterized the rainfall patterns over a large area, such as the state of Florida.

Project Background

The state of Florida is made up of five water management districts (WMD): Northwest Florida Water Management District (NWFWMD), South Florida Water Management District (SFWMD), Southwest Florida Water Management District (SWFWMD), St. Johns River Water

Management District (SJRWMD), and Suwannee River Water Management District (SRWMD). The WMDs range in size from about 1800 sq km (SRWMD) to about 2700 sq km (NWFWMD). Each WMD owns and operates their own rain gage network. Including 15-minute reporting National Weather Service (NWS) gages, 432 gages were available for this analysis. A map of the gage locations is shown in Figure 2.

Figure 2: Rain Gage Locations in Florida.

Preprocessing Radar Data

After integrating 15 months of raw radar data (Figure 1), locations of hybrid scan discontinuities, 230-km limit discontinuities and ground clutter were identified. These errors were corrected time step by time step using NEXRAIN's geographical information systems (GIS) algorithms. Discontinuities over the ocean were not addressed. After radar data were put through the GIS algorithms, the data were integrated over an entire month and quality checked to make sure that there are no additional radar errors in the dataset.

The top portion of Figure 3 shows minor hybrid scan discontinuities around the radar locations, a discontinuity at the 230-km extent of the radar and some locations of ground clutter for August 2002. The bottom portion of Figure 3 shows the result of the GIS algorithms, where the discontinuities are significantly minimized and the ground clutter has been suppressed.

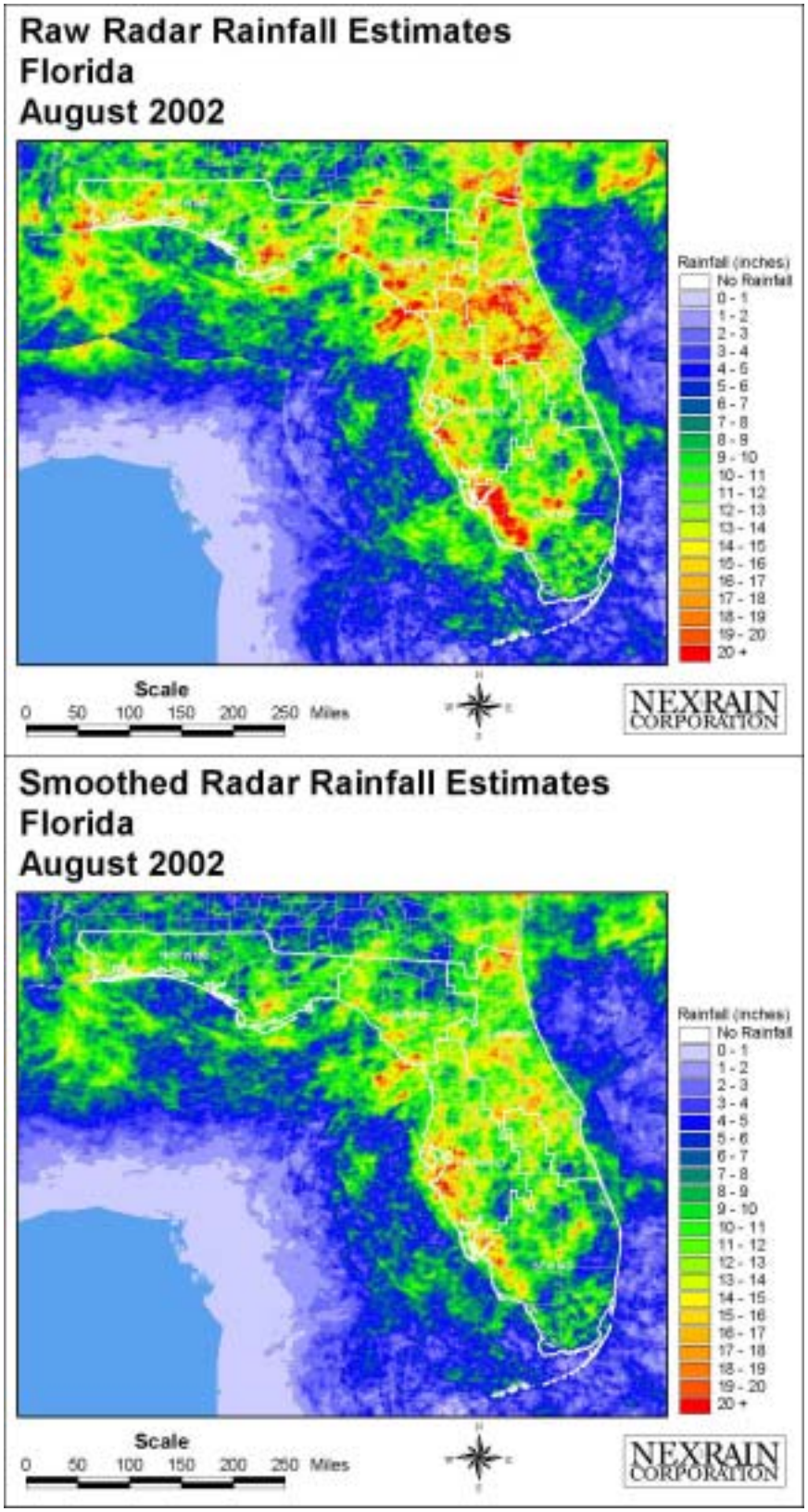

Figure 3: Before (Raw) and After (Smoothed) Radar Rainfall Estimates for August 2002.

Radar Adjustment Methodology

Gage data from all five WMDs and the NWS were obtained and quality checked for July 1998 and August 2002 (NEXRAIN is in the process of creating a gage-adjusted radar rainfall dataset from 1995 to present and these two months were chosen for illustrative purposes). While 432 gages were potentially available from all districts, the actual number of gages was always less. For instance, NWS data were not available at the time of the analysis for August 2002 and a total of 276 gages were used in that month's analysis. In July 1998, archived records for SRWMD gages were not available and 188 gages were used in the analysis.

For both months, gage data that were not consistent with the radar rainfall estimates and were not consistent with nearby gage estimates were excluded from the analysis. For instance, if a gage appeared to be plugged or if the timing of the reported rainfall from a gage were different than nearby gages, the gage with the questionable data was removed from the analysis.

NEXRAIN initially used a uniform gage-radar ratio for the radar adjustment algorithms. The procedure determines a simple ratio during each storm event by dividing the average rainfall measured at all of the valid rain gages by the average radar rainfall estimates at the radar pixels over the rain gages. This gage-radar ratio is then multiplied by the radar fields during the storm event and the result is a gage-adjusted radar rainfall dataset that maintains the spatial signature of the radar data while incorporating the volume estimates from the rain gage network. This procedure has been successfully employed in numerous studies (Hoblit and Curtis 2000, Hoblit and Curtis 2001).

These initial results showed that a uniform gage-radar ratio was not able to accurately characterize the rainfall across the entire state, because meteorological conditions at any given time can be drastically different depending on location within the state. Instead, NEXRAIN employed a modified version of spatial adjustment algorithm originally developed by Brandes (1975) and updated by NEXRAIN for use in areas with intense rain cells (Hoblit et al. 2002). The method determines spatially variable ratios at each pixel at each time step. The ratio at each pixel is determined by employing a weighted average of the ratios at nearby gages. Gages located closer to the pixel are given more weight and gages located farther than a predefined distance (radius of influence) are not used in the analysis. The weights are determined by a Gaussian function applied to the great circle distance between the gages and the radar pixel. This spatially variable adjustment technique does not force the radar data to match gage data at the gage locations.

For spatially variable adjustment of radar data, the use of a small radius of influence can force the radar data to approach the rain gage estimate at each rain gage. Unfortunately, this will also cause the spatial structure in the radar data field to be compromised, as the radar field is warped to match the rain gage estimates. For the Florida study, the radius of influence was set to 100 km for each study period. Using a large radius of influence incorporates a large number of gages for the analysis at each pixel. With a large radius of influence, the radar data are softly warped so that, on average, the gage-adjusted radar rainfall estimates over each WMD are closely aligned with the total gage rainfall estimates at the gage locations.

Results

Figure 4 shows the gage-adjusted radar rainfall estimates for the July 1998 study period. All discontinuities were removed and the ground clutter was suppressed in the preprocessing of

the radar data by the GIS algorithms. The spatial adjustment algorithm softly warped the radar rainfall estimates so that, on average, the gage-adjusted radar rainfall estimates are very similar to the rain gage estimates over each WMD. The algorithm also ensures that the spatial signature of the radar data is not compromised.

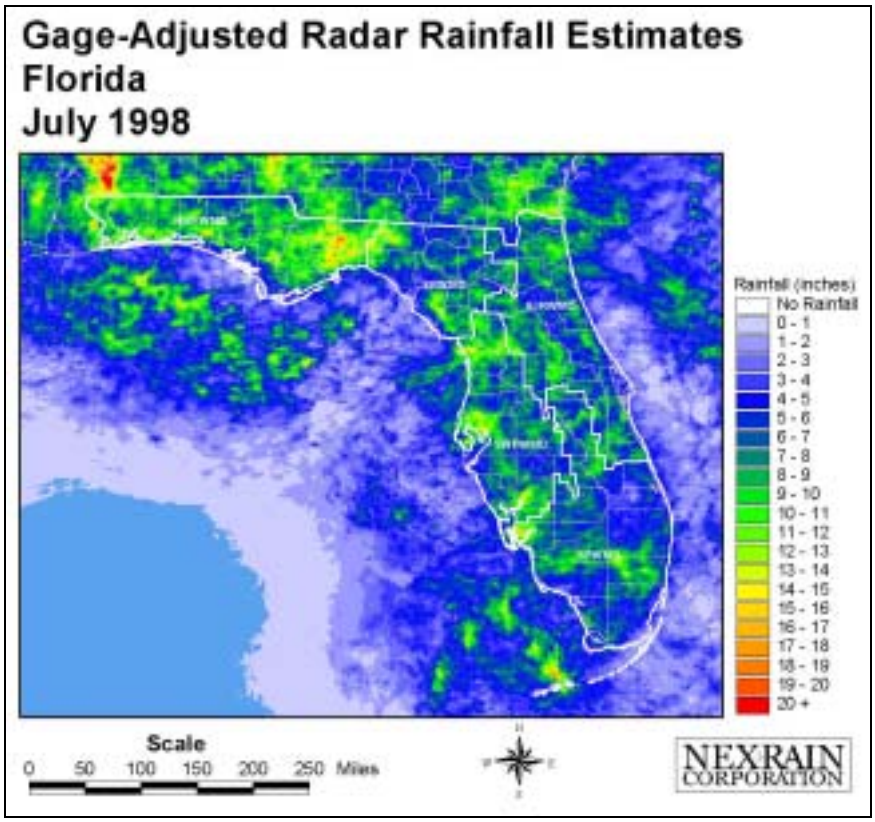

Figure 4: Gage-Adjusted Radar Rainfall Estimates for July 1998.

Figure 5 shows the average accumulation plot and scatterplot for the 188 gages used in the analysis (gages were not available from SRWMD). The average accumulation plot compares the accumulated average rainfall at the rain gages (*Gages*) with the accumulated average gage-adjusted radar rainfall at the radar pixels over the rain gages (*Adj_Radar*). The *Adj_Radar* line closely follows the *Gages* line, indicating that, on average, the gage-adjusted radar rainfall estimates nearly match the rain gage estimates. The scatterplot compares the rainfall estimates at the gage and at the radar pixel over the rain gage for each of the 188 gages used in the study. The estimates do not line up on the 1:1 line, however, there is a high degree of correlation between the two rainfall estimates for all sets of data.

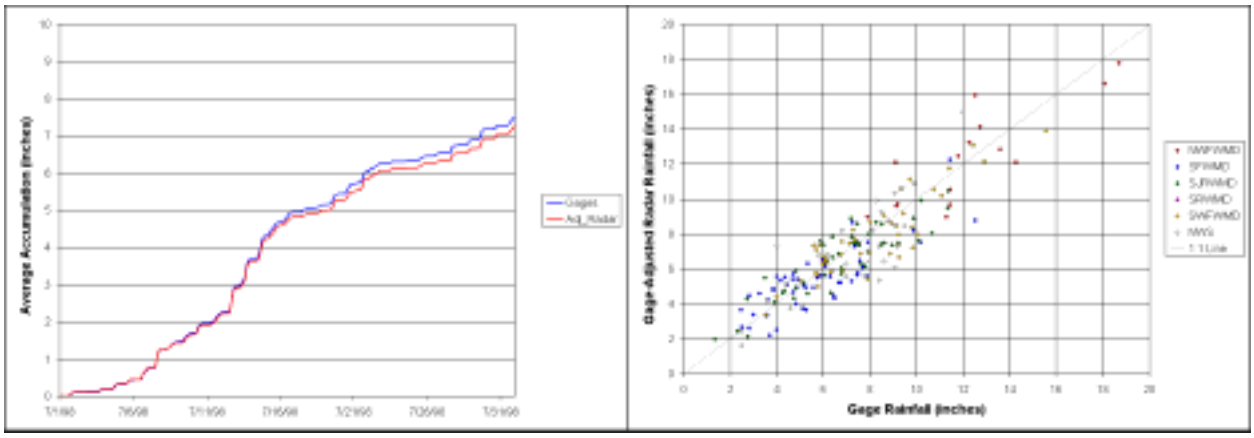

Figure 5: Average Accumulation (Left) and Scatterplot (Right) Results for July 1998.

Table 1 gives a summary of the average total rainfall at the gages versus the average total gage-adjusted radar rainfall estimates at the radar pixels over the rain gages for July 1998. In total, the gage-adjusted radar rainfall estimates for July 1998 were about 3% less than the rain gage estimates.

Table 1: Results (inches) for July 1998.

	July 1998		
	Gage	Adj_Radar	Difference
NWFWMD	12.24	12.30	1%
SFWMD	6.06	5.67	-6%
SJRWMD	7.21	6.98	-3%
SRWMD	-	-	-
SWFMWD	8.03	7.76	-3%
NWS	7.29	7.14	-2%
Total	**7.50**	**7.26**	**-3%**

Figure 6 shows the gage-adjusted radar rainfall estimates for the August 2002 study period. As with Figure 4 for July 1998, the preprocessing and adjustment algorithms have removed all of the radar rainfall discontinuities and created a softly warped dataset.

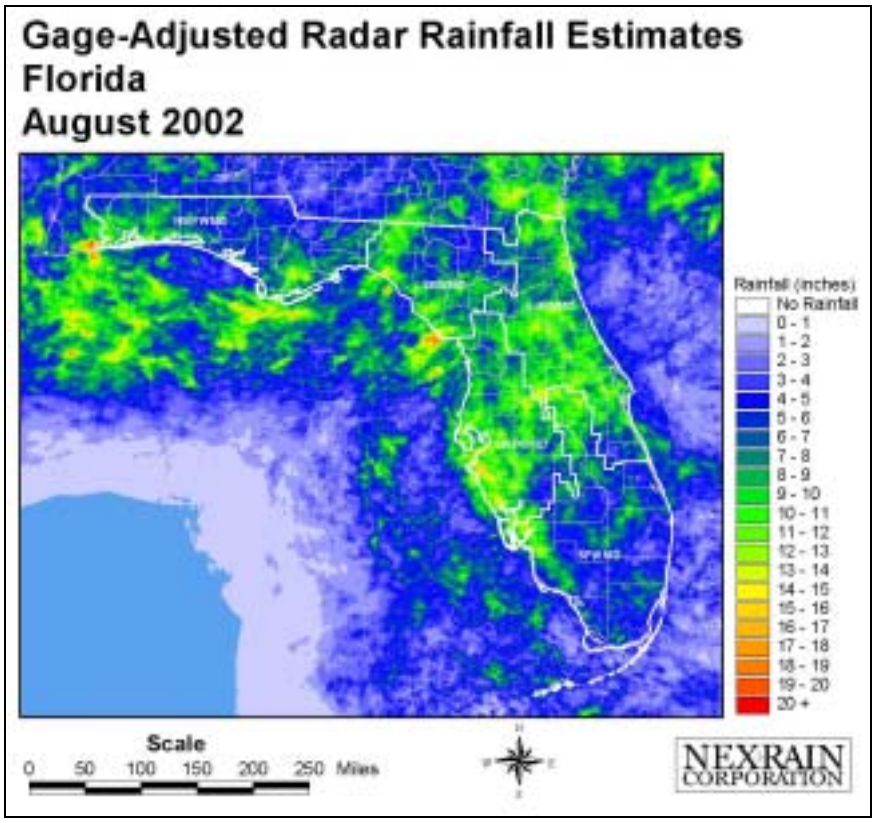

Figure 6: Gage-Adjusted Radar Rainfall Estimates for August 2002.

Figure 7 shows the average accumulation plot and scatterplot for the 276 gages used in the analysis (gages were not available from the NWS). The average accumulation plot is actually better than Figure 5, with the *Adj_Radar* line nearly following the *Gages* line throughout the month.

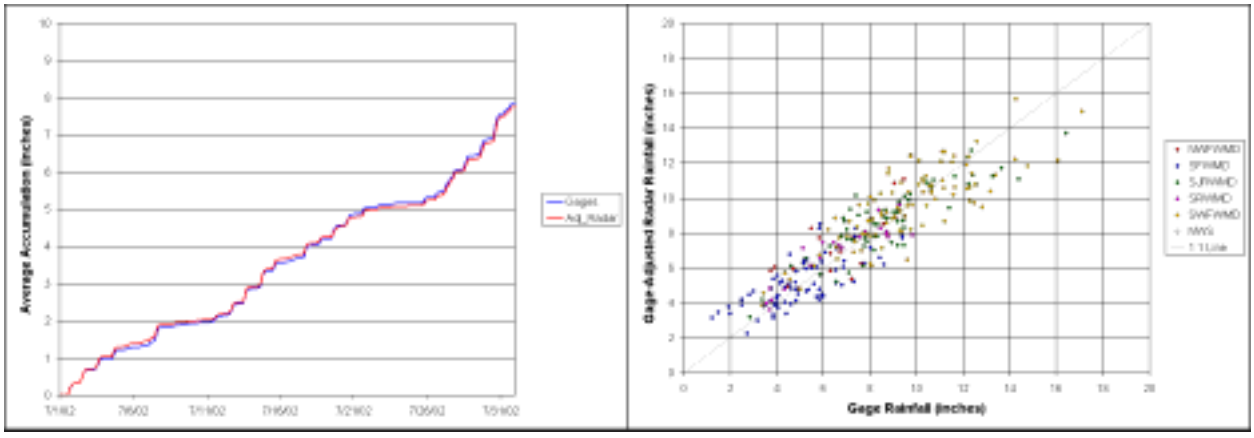

Figure 7: Average Accumulation (Left) and Scatterplot (Right) Results for August 2002.

Table 2 gives a summary of the average total rainfall at the gages versus the average total gage-adjusted radar rainfall estimates at the radar pixels over the rain gages for August 2002. In

total, the gage-adjusted radar rainfall estimates for August 2002 were about 1% less than the rain gage estimates.

Table 2: Results (inches) for August 2002.

	August 2002		
	Gage	Adj_Radar	Difference
NWFWMD	6.29	6.68	6%
SFWMD	4.97	5.10	3%
SJRWMD	8.85	8.77	-1%
SRWMD	6.62	6.91	4%
SWFMWD	10.05	9.57	-5%
NWS	-	-	-
Total	**7.84**	**7.74**	**-1%**

Although not presented in this paper, results from the other months in the study period (1995 to present) are very similar to July 1998 and August 2002.

Conclusion

Creating a seamless map of gage-adjusted radar rainfall estimates over the state of Florida produced the following conclusions:

1. The authors were able to remove discontinuities in the radar rainfall database using GIS algorithms. These discontinuities are evident in the mosaiced dataset that was used for this analysis, but the hybrid scan discontinuity will also be visible will data from a single WSR-88D.
2. For any gage-adjusted radar rainfall analysis, review of the gage data quality is extremely important.
3. For this study, the use of a large radius of influence with a spatially variable adjustment algorithm is an appropriate method to create a gage-adjusted radar rainfall dataset over a large area. Even though a large radius was used, the gage-adjusted radar rainfall estimates at individual locations within the state matched very well with rain gage estimates.

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