4.6 MULTI-SENSOR PRECIPITATION REANALYSIS

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1. INTRODUCTION

The network of Weather Surveillance Radar – 1988 Doppler (WSR-88D), commonly know as the Next Generation Weather Radar (NEXRAD), consists of approximately 140 sites in the Continenal U.S. Most radars have been operational for approximately 10 years and have been providing radar reflectivity estimates for the NEXRAD Precipitation Processing Subsystem (PPS) which produces radar-derived rainfall products in real time for forecasters in support of the National Weather Service's mission and external users. The PPS and follow-on multisensor precipitatoin estimation applications compute rainfall estimates in stages and, historically, the Stage III products are generated at the River Forecast Centers (RFCs). Recently, the Multisensor Precipitation Estimation (MPE) algorithm has replaced the Stage III algorithm. The MPE algorithm is an improvement on Stage III in several areas. The MPE algorithm delineates an effective radar coverage area based on seasonal radar climatology. The mosaicking scheme uses data from adjoining radars based on the radar sampling geometry. The algorithm provides analysis over the entire RFC, rather than mosaicking of radar-by-radar analysis. The algorithm has an improved mean-field bias correction, and it includes a new local bias correction procedure. Each of these improvements is designed to reduce or eliminate biases that are inherent in the radar rainfall estimates, but the algorithm is geared toward real-time operational implementation.

The NEXRAD data are available for an approximately 10 year record, which provides for a long term data set at high resolution both spatially and temporally. We have implemented the MPE algorithm with the historical NEXRAD data, the Digital Precipitation Array (DPA) products, in a reanalysis mode to develop a data set that is suited for long term climatological applications. We perform the reanalysis with the goal of reducing biases that continue to plague operational products. Reanalysis allows for several improvements to the historical radar rainfall products. One of the main improvements included in the reanalysis is to incorporate more in-situ measurements of rainfall which are important for the bias correction procedures. Higher quality and higher density rain gauge measurements will help improve the multisensor rainfall estimates. Further the reanalysis allows for detailed expriments for parameter tuning. All of these experiments will allow us to improve current estimates such that they are more suited for long term water resources and climate applications. We present preliminary results of our analysis over the Southeastern U.S (Figure 1).

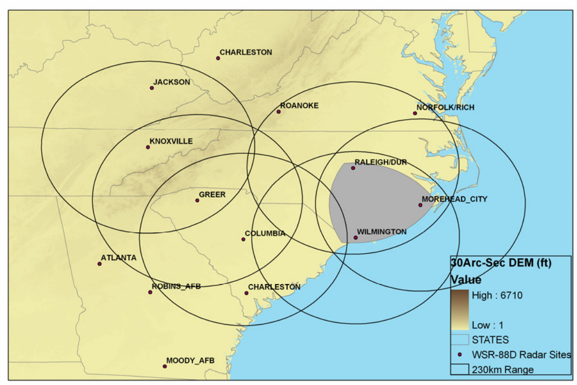

Figure 1: Radar coverage for the study region over North and South Carolina (Range rings are 230 km). The grey shaded region is the overlap region from the KRAX (Raleigh, NC), KMHX (Morehead City, NC), and the KLTX (Wilmington, NC) radars.

2. LONG TERM ANALYSIS

There have been relatively few attempts at deriving rainfall climatologies using radar data (e.g., Baeck and Smith, 1995, Croft et al., 1989, Nelson et al., 2003). However, most NEXRAD sites have been operational for about 10 years, and although this is not considered long enough for climatological studies, the NEXRAD data are available at high temporal and spatial resolution. The possible uses of the high resolution data are numerous but it is important to do preliminary investigations of the data to determine their strengths and weaknesses.

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2.1 *DPA*

The digital precipitation array (DPA) is the hourly running total radar rainfall estimate for a specific radar that is updated every volume scan. The DPA is computed by the PPS using the radar only reflectivity estimates and a transformation from polar coordinates to Cartesian coordinates (Hydrologic Rainfall Analysis Projection (HRAP)) (Fulton et al., 1998). Evaluation of DPA estimates has shown that it is subject to many types of biases (Smith et al., 1996, Young et al., 1999). These biases are due to hardware, microphysical and geophysical factors such as anomalous propagation, beam blockage, bright band contamination, radar calibration, and range dependency to name a few. At the hourly scale, it is difficult to find and eliminate these biases, but long term investigations show these biases well. Figure 2 shows accumulations of the DPA product over the warm season. Examples of bright band contamination at the KRAX (Raleigh, NC) radar and beam blockage from the KGSP (Greer, SC) radar are evident in these accumulations.

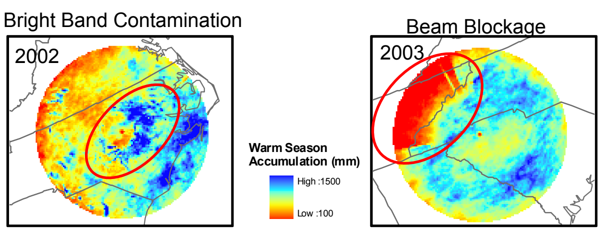

Figure 2: Example Biases Evident in DPA at the Raliegh, NC (KRAX) radar, and the Greer, SC (KGSP) radar.

Figure 3 shows the probability of detection (number of rainy hours during entire period), the conditional mean, and the mean as a function of range from the radar center for four radars over North and South Carolina. Evident in this analysis are biases due to range dependency. Beyond about 170 km from the radar, the detection of rainfall suffers. This bias is due to the radar sampling geometry and the fact that at the far range, the beam often overshoots clouds.

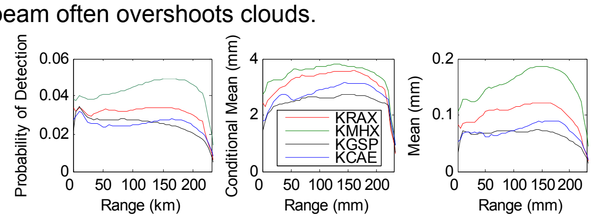

Figure 3: Probability of detection, conditional mean, and Mean rainfall as a function of range from the radar for four radars in the study region (KRAX, KMHX, KGSP, KCAE).

Figure 4 shows the fractional coverage of rainfall at each hour for a nine year period (1996-2004) in the overlap region of three radars in Figure 1, KRAX, KLTX, and KMHX (Raleigh, NC, Morehead City, NC, and Wilmington, NC). The fractional coverage of rainfall is determined by counting the number of pixels that report rain divided by the total number of pixels at any given hour. Here the total number of pixels is only the number of pixels in the grey overlap region. The figure shows there are many hours where one radar reports a fractional coverage of rainfall, but the other radar doesn't report any coverage at all. This is an indication of a non-precipitating reflectivity return such as anomalous propagation, ground clutter, or birds or insects. Each of these non-precipitating returns will cause a strong bias in the radar rainfall estimates over the long term.

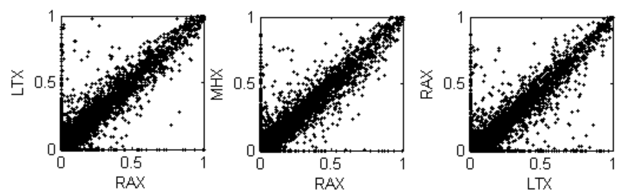

Figure 4: Fractional coverage of rainfall for the grey overlap region shown in Figure 1.

2.2 *Gauge*

The National Weather Service's (NWS) Office of Hydrologic Development (OHD) operates the Hydrometeorological Automated Data System (HADS), a real-time data acquisition and data distribution system for in-situ rain and stream gauges. There are over 10,000 sites available over the Continental U.S (CONUS). We are transferring these data from the NWS to NCDC for archive and are performing extensive quality control measures of these data (Kim and Nelson, 2005). We have used four years (2002-2005), initially, of HADS data for the reanalysis period and we will fill in the remaining years of data as they are transferred.

Although many in-situ data sets are available for the MPE algorithm, we focused on the HADS data because we spent extensive effort in determining the quality of this data set. Several studies have shown that the quality of the input rain gauge data is crucial for adjusting radar rainfall estimates (e.g. Steiner et al., 1999). Many of the quality control issues are reported in Kim and Nelson (2005), and some of the main points of the quality control are for example obtaining the correct time stamp, deciphering missing data and no data values, verifying the variable reported, and rain gauge resolution.

2.3 *MPE*

The Multi-sensor Precipitation Estimation (MPE) algorithm is designed for optimal merging of radar and rain gauge estimations. The MPE, run in real time, replaced the Stage III algorithm and was launched at the River Forecast Centers in 2002. Seo et al. (2002) describe a local bias correction procedure and Seo et al. (1999) describe a mean field bias correction procedure of the MPE for real time application and estimation and validation of parameters used in the MPE. This estimation procedure differs from our implementation in that it is geared for real time application. Our methodology however for parameter estimation and validation is very similar, but we have the luxury to add more variables and more complex algorithms in the reanalysis.

The MPE has been operational since 2002. Figure 5 shows the warm season accumulations of the MPE over our study region for 2002-2005 (2005 April-Aug only). This MPE product is taken from the National Center for Environmental Prediction (NCEP) Stage IV data. The NCEP Stage IV is a mosaic of all the RFC hourly and 6-hourly estimates from MPE and other applications. An initial look at the warm season accumulations shows that there still may be issues related to radar to radar calibration especially in 2002.

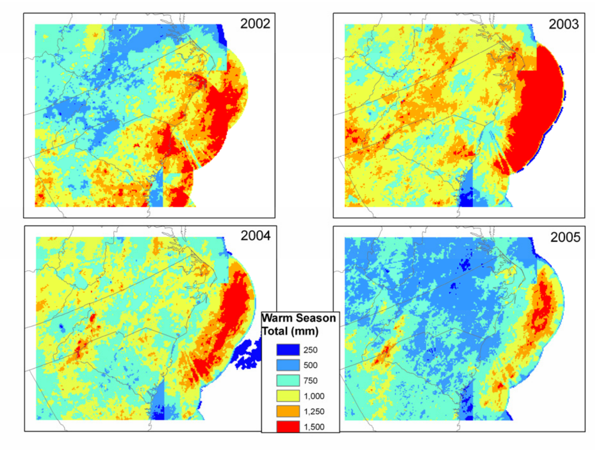

Figure 5: Four year warm season total rainfall for our study region for the NCEP Stage IV MPE product.

The MPE algorithm that we are implementing in reanalysis mode consists of four sub-algorithms for rain gauge estimation, radar rainfall mosaicking, radar rainfall bias adjustment, and optimal merging of radar and rain gauge estimates. A brief synopsis of the sub-algorithms is presented.

- Gmosaic: The gauge only product is based on rain gauge estimates and is obtained via the Single Optimal Estimation (Seo 1998a).
- Rmosaic: The radar product is a mosaic of the DPA data from multiple sites and is based on radar sampling geometry and beam blockage considerations.
- Bmosaic: The bias adjusted radar product is the rmosaic adjusted by the mean field bias (Seo et al., 1999).
- Mmosaic: The multi-sensor mosaic is a merged product from the gauge data and the bias adjusted radar rainfall data. The merging is based on the bi-variate extension of SOE (Seo 1998b).

3. SCIENCE AND OPERATIONAL QUESTIONS

3.1 *Parameter Estimation*

A major effort of reanalysis will be to tune the parameters of the MPE algorithm for long term climate analysis. Some of the important parameters involved in the MPR are related to the characteristics of rainfall which can be derived from its correlation function. Other parameters such as the number of rain gauges and the radius of influence used in the SOE and multi-sensor SOE are adaptable. Parameter estimation that is tuned for the long term will require many passes through the data for sensitivity analysis. We will consider how to maximize our processing power to be able to pass through all of the data quickly and efficiently.

3.2 *Validation*

Validation of the MPR product is one of the most important steps in the process. Users of the reanalysis product will be interested in a measure of uncertainty associated with the hourly estimate of rainfall for a given pixel. Validation is always difficult for an areal estimate of precipitation because of the highly variable process of rainfall at the given time scale. As of this point, validating the multi-sensor product is still under development.

3.3 *Input Gauge Data*

Although we have performed extensive quality control of the existing rain gauge data, we will be continually adding rain gauge data sources. The quality and density of the input rain gauge data is an important part of the MPR. We will investigate using precipitation data sources from the NCDC archive. The Cooperative Observers network is a dense network of daily precipitation reports. We will investigate how to use these data in the MPR. One method is to disaggregate the daily data to hourly reports. This method has shown some promise over the Arkansas-Red Basin River Forecast Center (ABRFC).

3.4 *Data Organization and Management*

Perhaps the most difficult part of the MPR will be how to run the algorithm for the CONUS. We will expand our region to the entire CONUS and many issues will arise related to the size of the input data. Figure 6 shows the data storage required for our study region. The MPR products necessitate almost 2 GB of storage per product per year. This is just for our study region that encompasses 250 x 201 HRAP pixels. The CONUS domain will encompass about 1800 x 900 HRAP pixels or about 30 times the data storage for each product. With 10 years of data, good data management and organization are critical.

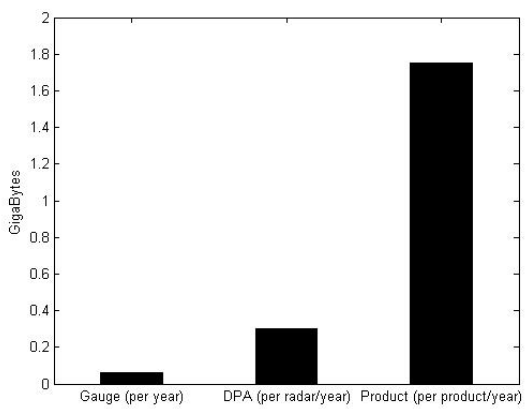

Figure 6: Data storage requirements for rain gauge data, DPA radar data, and MPE products for our study region.

3.5 *Future*

The future of the NEXRAD program is to install dual polarization capabilities at the radar sites. The dual polarization provides hope for improving the qualitative and quantitative aspects of the radar rainfall processing system. The NCDC will be the archive for the new dual polarized NEXRAD data and we will have a plan to include or replace these data in the MPR activity.

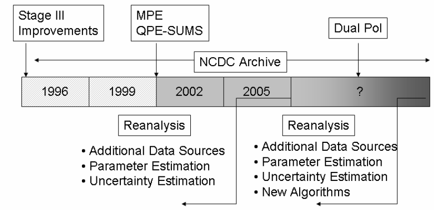

Figure 7: Future activities of MPR with changes in the NEXRAD precipitation processing algorithm.

4. SUMMARY

The main objective of the MPR is to generate an historical precipitation data set that is suited for climate applications. The data set will be useful for many other applications. We are implementing the NWS MPE algorithm in a reanalysis mode to tune the radar rainfall data for long term studies. The radar rainfall data are contaminated with many different biases and the MPE algorithm attempts to reduce or eliminate these biases. With 10 years of data at the 4x4 km spatial resolution, the data set will be valuable for many applications like drought studies, flood management, water supply, hydrologic design, and many others.

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