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Multi-scale Evaluation and Analysis of Precipitation Patterns over the Mississippi Delta

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Abstract

The Mississippi River floodplain in northwestern Mississippi, often referred to as the Mississippi Delta, is extremely important for regional economic stability and growth due to the widespread agriculture in the area. The region is unique in that there are currently three sources of precipitation measurements available: (1) radar-derived precipitation estimates from National Weather Service (NWS) NEXRAD network, surface observations from NWS recording stations, and surface observations from US Department of Agriculture (USDA) Soil Climate Analysis Network (SCAN) recording stations. In terms of water resource management and climatological precipitation research, quantitatively defining the biases associated with available precipitation data sources is critical in choosing which source to use for a given application. Additionally, due to the importance of precipitation in agriculture along with recent drought in the Mississippi Delta region, precipitation patterns should be reevaluated in terms of duration frequency, and extent. The inclusion of long-term data from surface gages along with shorter-term but higher resolution radar-derived rainfall estimates allow for a detailed analysis of past and current precipitation trends. This will lead to a better understanding of rainfall trends and patterns and potentially better prediction of future rainfall.

1. Project Overview

The Mississippi River floodplain in northwestern Mississippi, eastern Arkansas, and northeastern Louisiana is a key agricultural region in the southern United States. Often referred to as the Mississippi Delta, despite being an alluvial plain, the region is characterized by extremely deep, rich soils deposited through repeated flooding of the Mississippi River over the past millennia. The area is so conducive to crop production that 80% of Mississippi's agricultural products originate in the Delta region (Delta Council, 2005), which is considerable since Mississippi alone is the third largest producer of cotton and fourth largest producer of rice in the United States. In addition, agriculture in the Mississippi Delta comprises roughly 33% of Mississippi's total cash receipts; therefore, both local and state economies are highly dependent on agricultural production and stability. The same is true for Arkansas, where the Mississippi Delta is the primary agricultural center of the state.

Agriculture is known to be highly dependent on climatological variables related to the surface energy and water budgets, namely temperature and precipitation. Surface temperature (and the associated solar radiation flux) drives the photosynthetic process, leading to biomass increase and fruit production, while precipitation is necessary to maintain soil moisture for transpiration and latent heat fluxes from the surface. As a result, knowledge of the patterns of these climatological variables over monthly, seasonal, and annual scales is crucial in determining near- and long-term agricultural sustainability. This is especially true in light of possible climate change scenarios, in which the surface energy and water balances may be modified through global warming. This can have far reaching consequences on agricultural (Adams et al., 1990; Adams et al., 1995) and related economic development and stability (Rosenzweig and Parry, 1994), especially in the Mississippi Delta where agriculture is a cornerstone of the regional economy.

Of the climatological variables important to agriculture in the Mississippi Delta, precipitation is arguably the most important due to the high rates of evapotranspiration during the growing season, as well as the moisture required for local crops to succeed. However, precipitation is perhaps the most difficult climate variable to predict with respect to depth and coverage due to the myriad climatological and observational factors involved, especially during the summer growing season when small-scale convective events provide a majority of the precipitation. Due to this, precipitation research is and has been of key importance to the maintenance and development of agriculture and water resource guidelines in the Mississippi Delta.

The best way to improve climatological and meteorological predictions of precipitation over an area is to first improve the observation capabilities. The Mississippi Delta has a distinct advantage in this respect in that there are currently three sources of precipitation measurements available: (1) radar-derived precipitation estimates from National Weather Service (NWS) NEXRAD Doppler radars, (2) surface observations from NWS recording stations, and (3) surface observations from US Department of Agriculture (USDA) Soil Climate Analysis Network (SCAN) recording stations. Each of these data sources provides independent hourly measurements/estimates of precipitation that are used in both operational and research applications. However, despite the advantageous of having several precipitation data sources, it is not known how the data sources compare with each other. This information is vital since radar-derived estimates have the potential to be used along with or in place of existing gauge-derived estimates to improve precipitation representation in related applications.

The primary objective of this project is to quantitatively describe the biases associated with three available precipitation measurement and estimation sources in the Mississippi Delta region: the NWS and SCAN surface gauge-based networks and radar-derived NEXRAD precipitation estimates. This will include analysis of individual patterns of precipitation recorded by each source, as well as comparative differences between each. Results will provide information regarding the general biases associated with the observations so that the data sources can be used interchangeably in operational and research initiatives.

Understanding the spatial and temporal patterns of precipitation over an area can provide invaluable information regarding local and regional surface and groundwater availability. Many water resource managers rely on estimates of total rainfall based on historical averages; however, this information is limited as it does not directly include frequency or duration of precipitation. As a result, the secondary objective of this project is to define the probability of precipitation over the Mississippi Delta. By incorporating information from the results of the primary objective, a high-resolution product based on the radar-derived precipitation product will be developed to give better quantification of rainfall over the region. Results of this project will provide detailed information regarding precipitation patterns over the Mississippi Delta, allowing agriculture and water resource managers to make more accurate local-scale predictions and assessments of water supply and availability.

2. Data Collection

The study area for this project is defined as those counties in northwestern Mississippi and southeastern Arkansas where greater than 75% of the land area is less than 80 meters above sea level and the percent of land area used as cropland is at least 50% (Figure 1). This delineation allows for the inclusion of a large portion of the agricultural area in Mississippi and Arkansas, while excluding similar areas in Tennessee and Louisiana where surface meteorological station density decreases.

Within the defined study region, three hourly precipitation measurement and estimation sources are incorporated into the analysis. The first is National Weather Service (NWS) surface recording stations, including both ASOS automated surface observation system (ASOS) and non-ASOS recording stations. There are 13 stations within the study region with valid recorded data between 1996-2006, based on the National Climatic Data Center (NCDC) quality control routines (Figure 2a). The second data source includes Soil Climate Analysis Network (SCAN) sites, of which 13 surface recording stations were included in the study (USDA, 2006; Figure 2b). Again, only those stations with valid data between 1996-2006 were included. Although there is a relatively high spatial density of SCAN and NWS sites in the study area, it should be pointed out that not all stations have complete records between 1996-2006. This is especially true of the SCAN stations, where over half of the stations began recording precipitation over the last half of the study period. In an effort to include all available information in the analyses, especially with regards to recent observations, these stations were not removed from the analysis.

The third precipitation data source used in this project is multi-sensor precipitation estimates, derived from hourly WSR-88D data (Weather Surveillance Radar – 1988 Doppler; details of the methods and limitations of the products can be found in Fulton et al. [1998]). Radar-based precipitation estimates have become a useful and valuable tool in hydrometeorological research because of their high spatial and temporal resolution. This is especially true in research related to small-scale or intense precipitation variability and distributed hydrologic modeling. However, since radar is a remotely sensed platform with inherent, though understood, limitations (i.e., beam blockage, false return signals, truncation error, etc.), certain care must be taken while working with related data fields. Although the NWS has developed algorithms designed to minimize the error in associated precipitation estimates, it is difficult to fully quantify and remove these errors; however, the study area for this project is unique in that it lies within the coverage of three independent radar installations (Figure 2c). This minimizes potential errors resulting from faults with a single radar, while the low elevation of the region further minimizes issues related to beam blockage.

Multi-sensor data are produced by combining hourly radar precipitation estimates (a.k.a., Stage I data), in the form of a digital precipitation array (DPA), with select hourly surface-based observations. The surface observations are used to calculate a corrective mean field gauge-radar bias using a Kalman filtering approach, which is a local adjustment to the radar-derived precipitation field (Smith and Krajewski, 1991). This is done for each individual radar coverage, resulting in corrected radar-based precipitation estimates, called Stage II data. The final process combines the individual corrected radar fields into a mosaic of coverages, resulting in a continuous field of multisensor precipitation estimates. These data, now labeled as a Stage III product, are manually quality controlled at NWS river forecast centers to remove areas of known contamination (Briedenbach et al., 1998; NOAA/NWS, 2007).

In recent years the Office of Hydrologic Development (OHD) of the NWS has made a transition from the Stage III processing algorithms to the updated Multisensor Precipitation Estimator (MPE) algorithm. The greatest advantage of the MPE is its ability to incorporate future satellite-based precipitation estimation products (Kondragunta and Seo, 2004). Despite the fact that the algorithm used to calculate the precipitation estimates has changed during the study period for this project, no correction has been made to adjust either the data or the study period. It is the variations in the precipitation time series resulting from these biases that are to be quantified through this study.

Stage III and MPE precipitation estimates are provided by the NWS in XMRG format, and are projected in the Hydrologic Rainfall Analysis Project (HRAP) coordinate system. The

HRAP coordinate system is a polar stereographic projection centered at 60°N / 105°W, with a nominal 4x4 km grid resolution. For the purposes of this study, the multisensor precipitation estimates were decoded such that the latitude and longitude of the respective HRAP grid cell center was associated with the corresponding precipitation value.

3. Methodology

3.1 Primary Objective

3.1.1 Point Analysis Techniques

Hourly precipitation analysis involved statistical descriptions of hourly precipitation data for the SCAN and multi-sensor estimates, along with calculation of correlation coefficients between associated time series'. The NWS data were not included in the hourly analysis because only one of the included NWS observing gauges (Station 223627) measured in true hundredths of an inch while all other sites measured in tenths of an inch. This same station is used to calculate mean field biases in the multi-sensor precipitation product; therefore, the inherent statistical correlation with the radar field prohibits its use in direct hourly comparisons.

For hourly comparisons between the multi-sensor and SCAN networks, data for the nearest multi-sensor grid cell to each SCAN gauge was used. Only those gauges inside the study area were used, narrowing the number of SCAN stations used for analysis to nine (Figure 2). Descriptive statistics were calculated for both the multi-sensor and SCAN precipitation values assuming the data were gamma distributed, such that the associated shape (α) and scale (β) parameters were used to calculate the associated expected value ($\alpha\beta$) and variance ($\alpha\beta^2$) of the individual distributions (Wilks, 2006). The shape and scale parameters were calculated using the maximum likelihood approximation method from Greenwood and Durand (1960).

Precipitation data are inherently highly skewed, making direct calculation of the correlation coefficient between data impractical. Additionally, Gunst (1995) showed that if temporal trends and autocorrelation exist within a time series, the associated correlations will overestimate the true spatial correlation. Despite this, the use of statistical correlation to quantify the spatial structure of precipitation is well documented (Zawadzki, 1973). However, Stedinger (1981) showed that improved correlation values can be obtained if the skewed variables are logarithmically transformed, while Shimizu (1993) demonstrated that such a technique is indeed valid for analysis of precipitation data.

Habib et al. (2001) quantify the usefulness and robustness of using the bivariate mixed-lognormal distribution for comparison of precipitation time series. Consequently, the requisite calculation of the correlation coefficients between hourly multi-sensor and SCAN data was done using the method set forth by Shimizu (1993). This method involves transforming the associated precipitation time series to a log-normal distribution, separating the paired data into four distinct cases ([1] zero/zero, [2] zero/non-zero, [3] non-zero/zero, and [4] non-zero/non-zero), calculating the variances and means of the log-normal variables using expressions described in Shimizu (1993), and then incorporating the calculated values into the standard expression for the population correlation coefficient.

Daily comparisons between the multi-sensor and SCAN time series was done by summing up the associated hourly values from midnight to midnight local standard time (LST). Daily analysis was necessary because it is a common temporal resolution used in hydrologic and water resource applications, and because it reduces small-scale variations in the data that may influence statistical comparisons. Using the daily data, basic statistical indices were calculated for each paired time series including difference (multi-sensor – SCAN), ratio (multi-sensor / SCAN), and percent difference ([multi-sensor – SCAN] / multi-sensor). These indices, specifically the ratios and percent differences, have a high mathematical sensitivity to low or zero precipitation values; therefore, only non-zero paired precipitation values were included in the analysis. This can potentially remove a large portion of the dataset, but allows for a more precise description and comparison of rainfall when it does occur.

3.1.2 AREA-AVERAGED ANALYSIS TECHNIQUES

For spatial analysis purposes, it was necessary to calculate hourly mean areal precipitation values for the NWS and SCAN surface networks over the study area. This was done by first interpolating all available station data for a given hour from each network onto the same HRAP grid used by the multi-sensor product. An inverse-distance weighting algorithm was used for the interpolation due to its inherent simplicity and widespread use. For the interpolation, the maximum and minimum number of points used to calculate precipitation at a given grid cell was five and three, respectively, with a maximum search radius of 100 km. After interpolating the hourly point data into hourly grids, the grid values were averaged to obtain hourly mean areal precipitation values.

Although other methods for interpolation could have been used, such as Kriging or Theissen polygons, the issue of data availability was an issue. During any given hour the number of available data points in either network could change depending on period of record, recording error, or station malfunction; therefore, a simple yet robust interpolation procedure was considered more desirable since each interpolation required a reassessment of the available data.

Once hourly mean areal precipitation values were calculated over the study region for all three data sources, daily total precipitation was calculated to make data analysis and representation more efficient and also to minimize inherent measurement noise in the respective datasets. This was done by summing hourly values of precipitation from midnight to midnight LST. After summing the data into daily sums, it was noticed that the NWS surface data contained a large number of missing values and a small number of zero values as compared to the other two datasets. It appeared that, in general, if no precipitation was reported at a NWS station, instead of recording a zero a missing record was included. This led to substantial inconsistencies between the descriptive statistical measures of the datasets; therefore, to maintain as much consistency as possible during the analysis, all records of zero daily total precipitation were removed from both the SCAN and multi-sensor products. In this way, only days with above-zero precipitation were included in the analysis.

3.2 Secondary Objective

Water resources in the Yazoo River watershed, which comprises a large part of the Mississippi Delta, are important because of the widespread agriculture in the basin. The region is characterized by extremely deep, rich soils deposited through repeated flooding of the Mississippi River. Although the region receives 130-140 cm of precipitation annually, high rates of evapotranspiration during the summer lead to a need for agricultural irrigation. This is especially true for catfish and rice production, which require an average of 600mm day^{-1} and 900mm day^{-1} of water, respectively, to maintain production (YMD, 2006). Due to this, precipitation research is and has been of key importance to the maintenance and development of agriculture in the Mississippi Delta.

Radar-based precipitation estimates from the Stage III and MPE algorithms have become a valuable tool in hydrometeorological research due to their high spatial and temporal resolution (Young et al., 2000; Fuelberg et al., 2002). This is especially true in research related to local-scale precipitation variability, where surface gage networks lack the spatial density to measure detailed variations in rainfall. Although the Stage III and MPE precipitation estimates provide an excellent platform for studying precipitation distribution, there does exist some uncertainty in actual hourly precipitation values. This uncertainty arises due to both random and systematic errors in the multi-sensor product.

To lessen the effect of random error and measurement variability, as well as to make data analysis and representation more efficient, daily precipitation totals were used for this project instead of hourly estimates. These were calculated by summing all values for each day from 0000Z to 2300Z so that time zone and daylight savings time could be ignored. Additionally, as a final quality control check against non-random systematic errors, any daily precipitation totals that were more than three standard deviations above the overall mean for each individual basin were flagged. These values were then manually verified using external data sources, and if found to be caused by non-physical processes, substituted with a missing value identifier. Although this procedure cannot completely remove the effect of systematic errors resulting from sensor or algorithmic issues, it can minimize their impact on the data set and associated analysis.

4. Project Results

4.1 Primary Objective

4.1.1 Hourly Point-scale Analysis

Precipitation patterns over the lower Mississippi River alluvial valley have a distinct seasonal pattern, with the greatest depth of precipitation occurring in the late fall and early winter and the lowest occurring in the summer. This seasonality is primarily a result of the latitude of the study area, such that cool season weather patterns are based on a more baroclinic environment, leading to a higher frequency of frontal convection and stratiform precipitation, while the warm season is dominated by a more barotropic environment with scattered cumuliform precipitation. Based on this pattern, the point-scale analysis of hourly precipitation values from the multi-sensor and SCAN observation platforms is done separately for the warm season (April - September) and cool season (October – March). This approach will provide more information as to how the SCAN and multi-sensor data sources compare under different precipitation patterns. During the warm season, the multi-sensor precipitation estimates are greater than the associated SCAN observations at all locations (μ = 0.07; Table 1). Although there are too few points to determine spatial influences, it should be noted that the greatest differences are found at sites 2086, 2032, and 2087 (0.17, 0.09, and 0.08 mm, respectively), all of which are located under the coverage of only the Jackson, Mississippi radar. This fact could indicate that precipitation estimates from the Jackson, Mississippi radar are biased towards higher values; however, further work is needed to verify that this is true. Variances between the data sources are roughly equal, although multi-sensor estimates are more dispersed at all locations relative to the associated SCAN values.

Correlation coefficients between the multi-sensor and SCAN data during the warm season are similar at all locations, ranging from ρ = 0.48 - 0.59 (μ = 0.55; Table 1). This shows that the data sources are only moderately correlated, the physical reasons for which are difficult to accurately determine. To truly verify a precipitation measurement a ground-truth value must be used for comparison, which is often assumed to be a surface-based observation. The fact that surface gauges often underestimate rainfall (due to issues such as wind undercatch, splashing, and evaporation) while radar-estimates tend to overestimate precipitation (due to assumptions in the Z-R relationship, false return signals, issues with frozen precipitation, etc.) leads one to conclude that the poor correlation between the SCAN and multi-sensor data is a combination of independent and additive errors.

During the cool season the differences between the SCAN and multi-sensor data sources are reduced, with average differences between the means and variances both equaling 0.01 mm (Table 1). Additionally, the correlation coefficients between the data sources increases substantially at all locations, ranging from $\rho = 0.59 - 0.72$. The increase in correlation and decrease in mean difference and dispersion is likely a result of a change to stratiform precipitation patterns over the study area. Under these conditions, precipitation rate is lower while droplet size becomes more uniform, which effectively decreases the errors associated with radar precipitation estimates. The issue of undercatch with the SCAN gauges may also decrease, although these changes are likely minimal. The end result is a closer approximation of precipitation rate and depth by the radar-based multi-sensor estimate, although unquantifiable errors from both data sources prohibit a higher correlation.

4.1.2 Daily Point-scale Analysis

Analysis of mean daily precipitation, calculated by summing the hourly rainfall values for each day, allows for a more general quantification of the biases between the surface and radar-based rainfall data sources by removing short-term variability from each dataset. Results show that the multi-sensor data are, on average, 0.31 mm day^{-1} higher than the SCAN values, indicating an overestimation by the multi-sensor product (Table 2). Again, the term overestimation may be a misnomer since a ground-truth precipitation value is unavailable. These results agree with the hourly analysis; however, the percent difference values are contrary to these results, showing the SCAN data as having an average bias of 38% above the multi-sensor estimates. The reasons for this incongruity stem from the sensitivity of the bias calculations at low precipitation values, such that a small difference relative to a small multi-sensor precipitation estimate can lead to large percent differences. What can be illustrated from these results is that at low daily precipitation depths, the surface-based SCAN gauges observe a greater precipitation depth than the multi-sensor product.

Looking at the warm and cold seasons separately shows that the differences between the data sources generally increases during the summer months and decreases during the winter months. During the warm season, the average difference increases to 0.59 mm day^{-1}; however, the magnitude of nearly all differences increases, despite the direction of the bias (Table 2). During the cool season the average difference decreases to -0.11 mm day^{-1}, which upon initial interpretation indicates that the multi-sensor data show a negative bias with respect to the SCAN data. The average percent difference during the cool season is substantially lower than during the warm season (-0.49 and -0.37 mm day^{-1}, respectively), which gives further credence to the possibility of precipitation overestimation by the SCAN gauges during stratiform-type precipitation events.

To minimize the effects of small precipitation values on the calculation of percent difference, the point-analysis is limited to instances in which the daily total precipitation given by the multi-sensor estimates is at least 25 mm day^{-1}. This will allow for an improved quantification of the measurement bias between the SCAN and multi-sensor precipitation data sources. The 25 mm day^{-1} criteria was chosen because it roughly corresponds to a natural break in the respective precipitation time series, an example of which is given in Figure 3, and also because it is a common value denoting a day with heavy precipitation.

Relative to all precipitation values meeting the above criteria, the difference between the SCAN and multi-sensor data sources increases to an average of 2.91 mm day^{-1} (Table 2) while the percent difference decreases substantially to 5%. The differences in daily precipitation depth during the warm and cold season are above and below this value (4.10 mm day^{-1} and 2.58 mm day^{-1}, respectively), which agrees with previous patterns. Unlike the analysis utilizing precipitation depths less than 25 mm day^{-1}, the multi-sensor estimates are shown to overestimate precipitation relative to the SCAN data. The percent difference values match this result, showing that multi-sensor estimates are, on average, 6% greater than SCAN observations during the cool season. This value is only slightly higher (7%) during the warm season, which indicates that at high daily precipitation depths, which commonly occur during the summer when cumuliform precipitation events are more common, the bias between the multi-sensor and surface-based SCAN networks is relatively small and stable.

4.1.3 Daily Mean Areal Precipitation Analysis

Due to the seasonality of the biases between the data sources described previously (maximum in warm season, minimum in cool season), a time series analysis of the biases over the entire study period was considered necessary. However, the large number of missing data points in the time series, along with the relatively random distribution of the missing values within the study period, did not allow for an accurate and reliable method of time series analysis. As a result, the data were subject to a more informal analysis based on running means and variances over the 1996-2006 study period. This was done by first calculating the differences between each data source, then standardizing the values by subtracting the overall means and dividing by the standard deviation. The results yielded three standardized time series with a mean of zero and a standard deviation of one for the NWS – SCAN, NWS – multi-sensor, and SCAN – multi-sensor data. To minimize inherent noise in the data while providing a good description of the relative patterns and variability of precipitation biases over the study period, a 100-day running mean and standard deviation were calculated for each set of paired data. Results from this analysis cannot be used to interpret absolute biases between the data sources since they have been normalized relative to the means, but are a good indication of how the biases change over the study period.

The bias time series of the NWS and SCAN data sources remains relatively constant throughout the study period, despite several high magnitude peaks in 2003. The 100-day running mean indicates that there was a maximum negative bias during the winter of 2001-2002 (-0.83 standard units), and a secondary minimum in the fall of 2002 (-0.49 standard units). Conversely, a maximum positive local bias occurred during the summer of 2002 (0.41 standard units), illustrating the seasonal variation in precipitation biases between these two data sets. The variability of this bias remained fairly high until the late summer of 2003 when it began to decrease markedly, most likely a result of an increase in the number of stations within the SCAN network.

The bias between the NWS and multi-sensor precipitation estimates shows a general decrease from 1996 to early 2003 before stabilizing throughout the remainder of the study period. This transition is a possible indication of a modification to the multi-sensor precipitation estimation process; however, the variability of the bias between the data shows no distinct change with the stabilization of the precipitation bias. Also, while there is a slight oscillatory pattern in the data after 2000, reflecting the seasonality of the bias (lower in the winter, higher in the summer), there is no apparent oscillation before this time. In fact, from late 1997 to late 2000, there was little change at all in the bias values other than a general decrease.

Regarding the SCAN and multi-sensor precipitation data, the same general pattern of decreasing bias from the beginning of the study period to early 2003 is apparent. This clearly shows that it is the multi-sensor precipitation estimates that have changed during this time and not the surface-based observation networks. Subsequent to early 2003, the biases between the SCAN and multi-sensor data sources becomes more consistent and is mirrored by a slight decrease in variability. This decrease in variability is likely a result of an increase in the number of SCAN observation sites, since there is also a slight decrease in variability in the NWS and SCAN precipitation biases. These results generally show that as a result of an increase in the density of the SCAN network and a modification to the multi-sensor precipitation processing system, the bias between the two datasets has become more stable and less variable over the study period.

4.2 Secondary Objective

4.2.1 Mean Annual and Monthly Precipitation Analysis

Precipitation in the Yazoo River watershed peaked in the early 2000s, centered on a maximum of 13.0mm day^{-1} in 2002. Interestingly, secondary peaks in 1997, 2004, and 2006 are accompanied by peaks in the mean hourly areal precipitation. Although correlations between these data are moderate (R^2 = 0.56), this does show that changes in the distribution of precipitation in the Yazoo River watershed may be as if not more important to overall water availability than variations in precipitation intensity. This is an important result, since high intensity precipitation over agricultural areas is often considered a negative due to heightened erosion processes and soil compaction. Regarding changes in frequency of precipitation over the Yazoo River watershed, the average number of hours with recorded precipitation per day varies only slightly, remaining between roughly 7 – 9 hours day^{-1}. The relationship between precipitation frequency and amount is weak ($R^2 = 0.39$), but does work to augment the statement that precipitation variability in this region is based more on precipitation frequency and extent and not precipitation intensity.

Monthly mean precipitation in the Yazoo River watershed shows no distinct seasonal pattern in mean daily precipitation, although there is a slight minimum during the late summer and early fall (6.6 - 6.7 mm day^{-1}). However, there are clearly defined summer maximums and minimums in precipitation frequency (11.45 hours day^{-1}) and extent (2645 km^{-2}), respectively, both centered on July. This pattern suggests that a high frequency of precipitation during the summer is countered by a low areal extent, similar to the cumuliform precipitation patterns seen in both the Savannah River watershed and the southern Florida region. However, during the winter the areal extent of precipitation in the Yazoo River basin overcomes the decrease in precipitation frequency, leading to a slight increase in overall monthly rainfall.

4.2.2 SEASONAL PRECIPITATION ANALYSIS

To better understand the patterns of precipitation over the study area, a detailed spatial analysis was done for the summer and winter months, defined as April through September and October through March, respectively. This separation marks an even division of the water year for the southeast US, and clearly marks the change in precipitation patterns given by the monthly mean values of precipitation amount, frequency, and areal extent.

Summer precipitation patterns in the Yazoo River watershed are fairly variable, with mean daily precipitation depths ranging from over 4.0 mm day^{-1} in the northeast to less than 2.0 mm day^{-1} in the south (Figure 4a). Precipitation frequency shows the same general pattern, although the range of values shows a lower relative difference (Figure 4b). These results show that higher intensity and more frequency rainfall occurs in the central and eastern edge of the basin, possibly due to the local influence of moisture from the Gulf of Mexico along with the influence of mesoscale and synoptic-scale boundaries. However, the high density of agriculture and the associated irrigation along the western edge of the basin, known as the lower Mississippi River alluvial valley, or locally as the Mississippi Delta, may have an influence on the given rainfall distribution.

Research has shown that agriculture in the western areas of the Yazoo River watershed can have an influence on regional weather variability through land use and vegetation patterns (Brown and Arnold, 1998). Specifically, soil type and vegetation can affect the energy and moisture fluxes into the atmospheric boundary layer through spatial variations in evapotranspiration, albedo, and surface heat transport (Hong et al., 1995; Segal et al., 1988; Ookouchi et al., 1984; Rabin et al., 1990; Mahfouf et al., 1987; Boyles et al., 2007). Work by Brown and Wax (2007) show that a temperature gradient exists between the eastern and western portions of the Yazoo River watershed, the former of which is the low-elevation floodplain of the Mississippi River. During the summer months, maximum daily temperatures within this section of the watershed are 0.5°C warmer than areas outside the Mississippi River floodplain, which could possibly effect precipitation patterns. Brown and Wax (2007) suggest that variations in soil type and/or soil moisture could be the cause of the temperature difference, primarily through variations in the surface heat fluxes. Based on analysis of the sandhill effect in the Savannah River basin, a similar phenomenon could be occurring within the Yazoo River watershed; therefore, further research into this topic is currently underway in an effort to better quantify precipitation patterns for water resource management and agriculture. Again, the multi-sensor precipitation product is ideally suited for this study, since the enhanced detail of the precipitation estimates can better indicate local-scale variations in rainfall.

The Yazoo River watershed is the only basin in this study that receives more precipitation during the winter (3.6 mm day^{-1}), due in part to the greater areal extent of precipitation over 3 mm day^{-1} (Figure 4c). This can be seen by a decrease in the range of mean daily precipitation values from 2.7 mm day^{-1} to 1.9 mm day^{-1}, relative to the warm season, due primarily to an increase in minimum precipitation. Precipitation over the region is consistently and uniformly high in both depth and frequency, with local maxima in the central parts of the basin (Figure 4c-d). This pattern is critically important to agriculture, the dominant economic resource of the region, in that extensive but moderate intensity rainfall is able to satisfy soil moisture requirements and groundwater recharge while minimizing soil compaction and erosion. This allows for a higher percentage of the precipitation to be stored in the groundwater system before running off into surface hydrologic features.

5. Future Research

Research has shown that agriculture can have an influence on regional weather variability through land use and vegetation patterns (Brown and Arnold, 1998). Specifically, soil type and vegetation play a key role in determining the dynamics of energy and moisture transport into the atmospheric boundary layer through spatial variations in evapotranspiration, albedo, and surface heat fluxes (Hong et al., 1995; Segal et al., 1988; Ookouchi et al., 1984; Rabin et al., 1990; Mahfouf et al., 1987; Boyles et al., 2007). These effects are clearly well documented, and can occur in various climate zones given weak synoptic forcing. Additionally, agricultural land use can influence the dynamics of the boundary layer through variations in surface roughness over the growing season, effectively modifying existing sub-synoptic and mesoscale flow regimes by varying the intensity of turbulent mixing through the radix layer.

The energy, moisture, and turbulent fluxes all have strong influences on the generation and strength of mesoscale circulations, and therefore precipitation. As a result, variations in land use and/or soil type can lead to changes in regional precipitation patterns (Anthes, 1984). Several studies have demonstrated the role of the sand-clay soil boundary in eastern North Carolina (a.k.a., the "Sandhill Effect") on mesoscale surface convergence and convective precipitation (Boyles et al., 2007; Koch and Ray, 1997). Similar soil contrasts exist within the lower Mississippi River alluvial valley, and results from Dyer (2008) indicate that precipitation patterns in and around the Mississippi Delta may be influenced by changes in land use, soil type, and/or soil moisture. Abnormal temperature variations exist in the region as a result of spatial variations in soil and vegetation (Raymond et al., 1994; Brown and Wax, 2007), which could be an indicator of possible boundary layer modification through surface influences, resulting in the generation of mesoscale circulations and precipitation.

The first future research topic involves the analysis of high-resolution precipitation data over the lower Mississippi River alluvial valley to determine if precipitation patterns are influenced by surface soil and/or vegetation variations. Initial findings indicate that a distinct dipole pattern exists with a rainfall minimum over the Mississippi Delta and a maximum approximately 150 km to the east (Figure 5). Further analysis of this pattern over a monthly and seasonal basis may provide information regarding the temporal and spatial extent of regional rainfall.

To better understand the causes of the observed rainfall distribution, it is necessary to perform a sensitivity analysis of convective forcing mechanisms and the associated precipitation generation. This type of study is best performed through numerical modeling; therefore, a second future project involves the use of the Weather Research and Forecasting (WRF) model to identify the surface and atmospheric mechanisms most responsible for the existing rainfall distribution. Although modeling studies have been carried out in other locations to examine the sensitivity of mesoscale circulations to surface characteristics (Mahfouf et al., 1987; Boyles et al., 2007; Hong et al., 1995), it is necessary to first study observed data to determine if a relationship is visible. Subsequent studies using mesoscale numerical models may then be appropriate to quantify the sensitivity of surface convergence zones to soil and vegetation. This strengthens the validity of performing an observational analysis of rainfall, followed by an associated analysis of simulated rainfall distribution over the same region. Results of this project will provide detailed information regarding precipitation patterns over the Mississippi Delta, allowing agriculture and water resource managers to make more accurate local-scale predictions and assessments of water supply and availability.

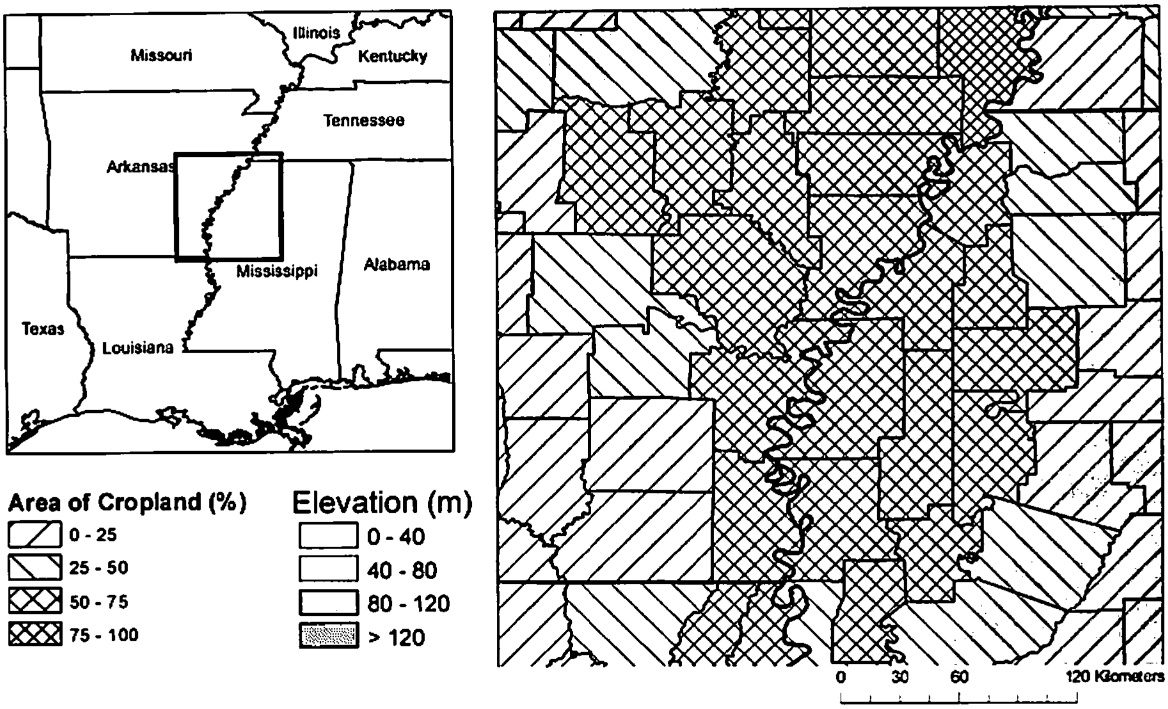

Figure 1. Topography and agriculture of Mississippi Delta region in northwest Mississippi and southeast Arkansas. Cutout shows location of study region in southern United States. [From Dyer (2008)]

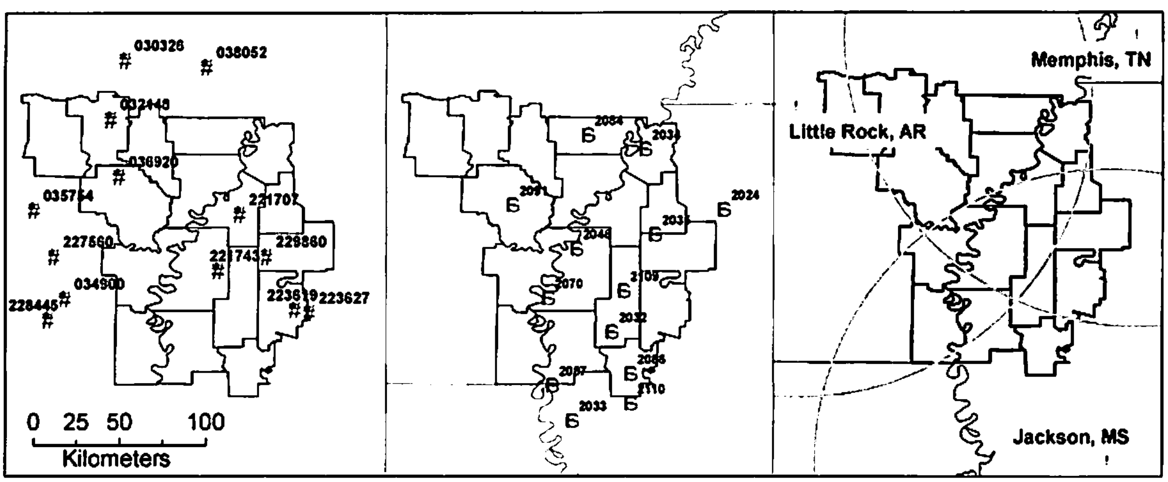

Figure 2. Distribution of (a) NWS surface recording gauges, (b) SCAN surface recording gauges, and (c) NEXRAD radar installations used to calculate radar-estimated precipitation values over the study region (circles indicate a 230 km radar coverage area for each installation). [From Dyer (2008)]

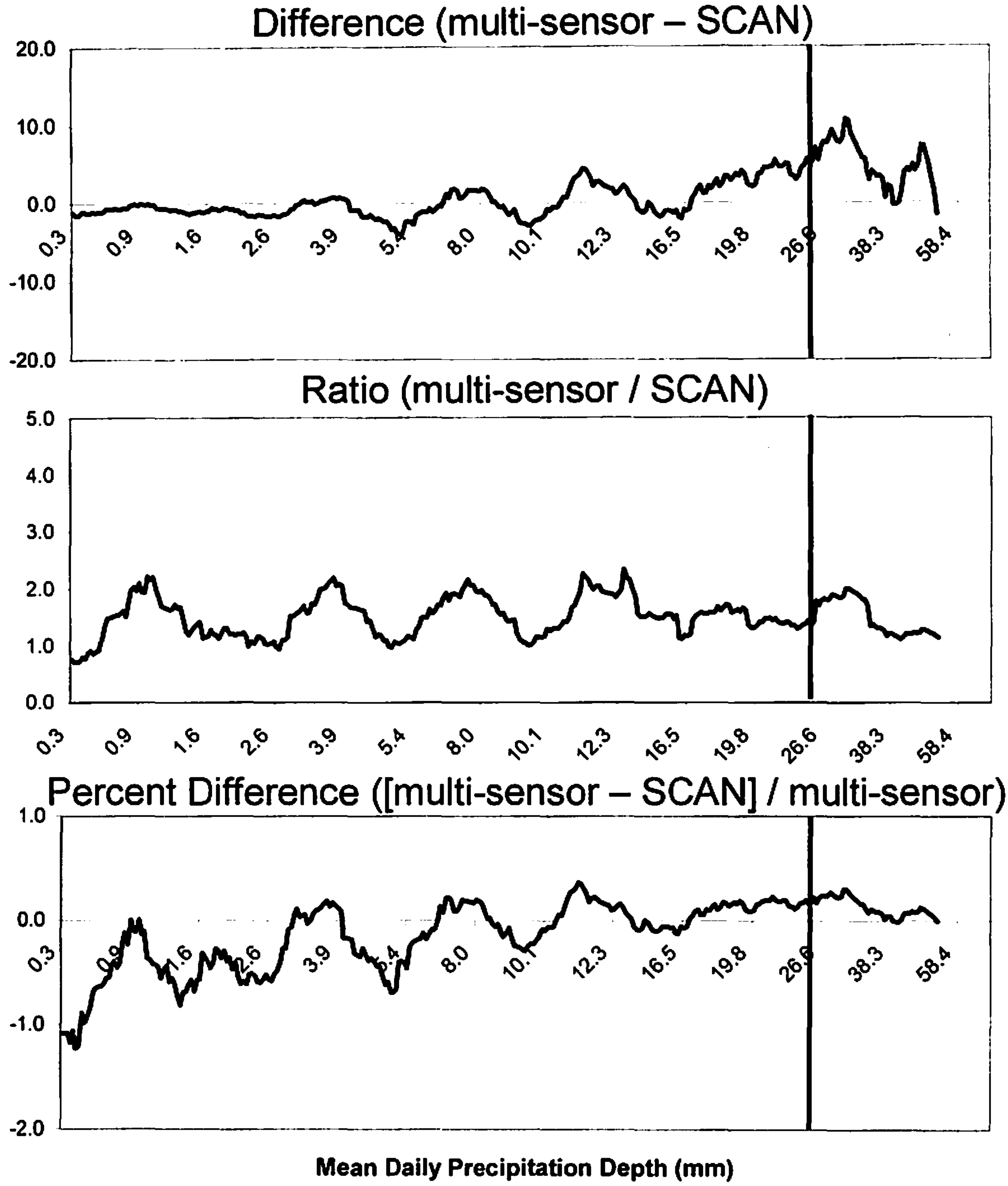

Figure 3. Difference, ratio, and percent difference values for precipitation over SCAN gauge 2046. Solid horizontal black lines denote a 20-point running mean for the respective time series, while the solid vertical lines indicate the 25 mm threshold. [From Dyer (2008)]

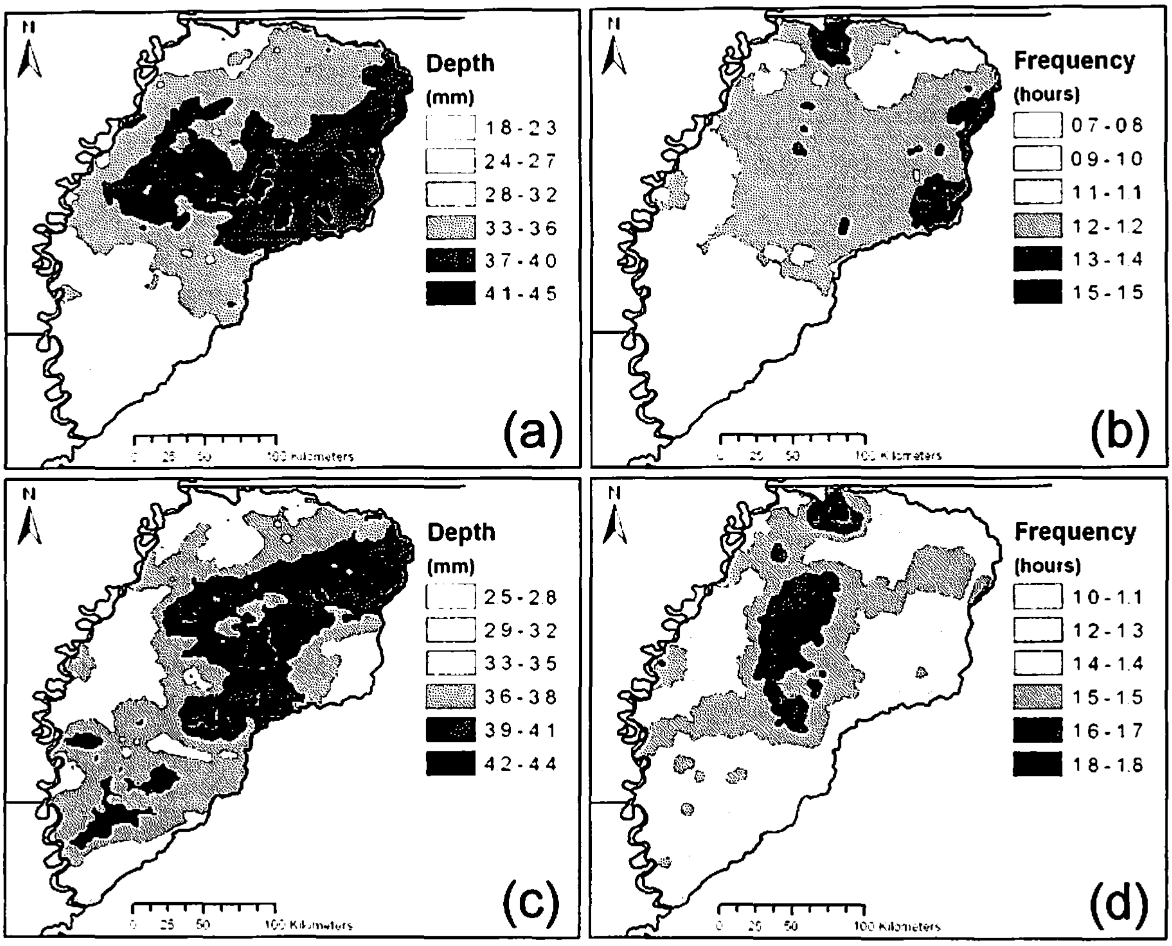

Fig. 4. Yazoo River watershed precipitation patterns for warm season (April – September) mean daily precipitation (a) depth and (b) frequency and cool season (October – March) mean daily precipitation (c) depth and (d) frequency. [From Dyer (2009a)]

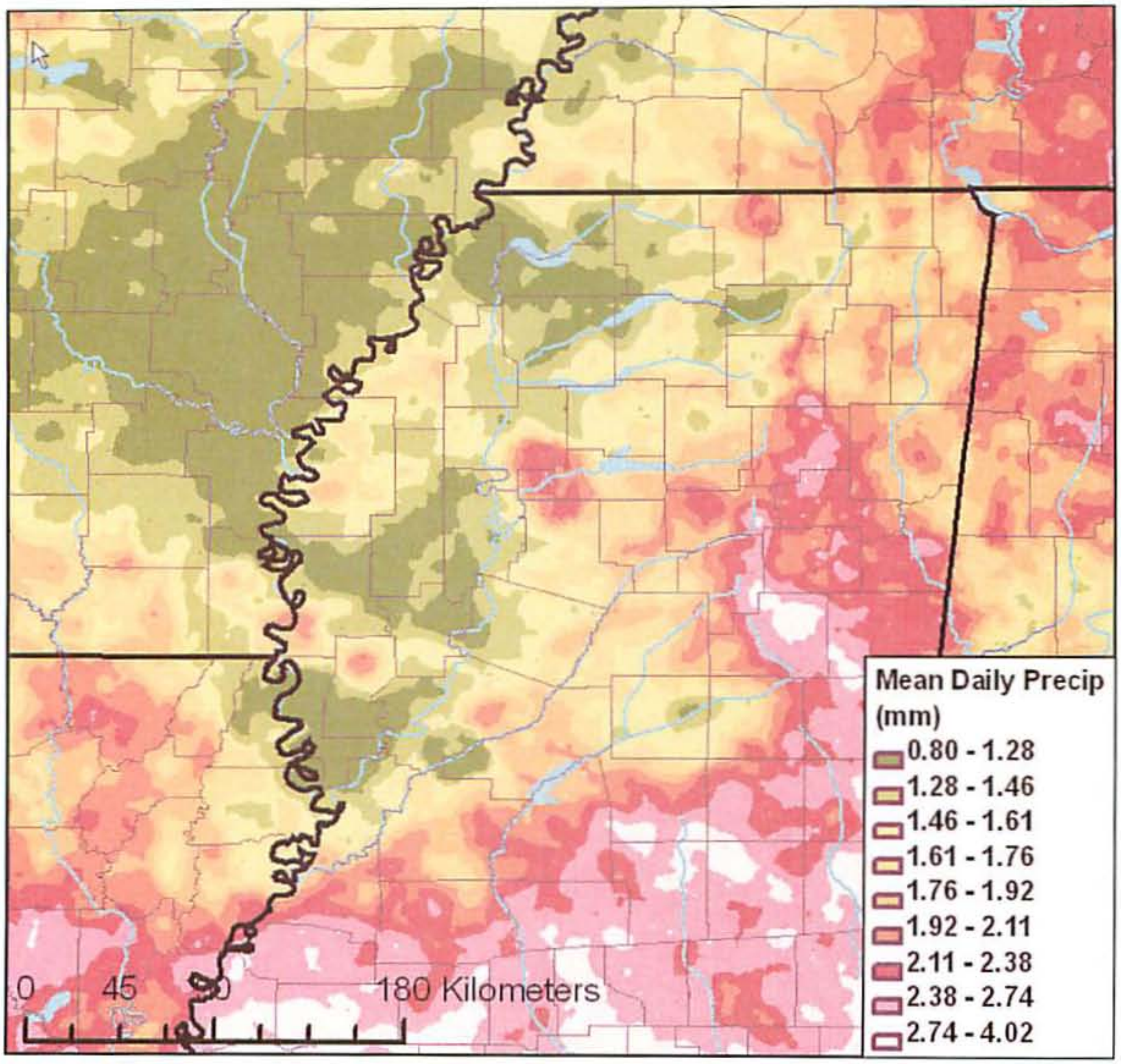

Figure 5. Mean daily precipitation (mm) over the Mississippi Delta and surrounding regions for all synoptically weak days from 1996-2007.

Table 1. Hourly mean, variance, and correlations for warm and cold-season precipitation at select SCAN stations and adjacent NEXRAD multi-sensor grid points. Mean and variance were calculated assuming a gamma distribution while correlations were calculated assuming a bivariate mixed-lognormal distribution. [From Dyer (2008)]

		Warm Season			Cool Season		
SCAN ID	Data source	Mean	Variance	Correlation	Mean	Variance	Correlation
2091	SCAN	0.11	0.02	0.55	0.39	0.17	0.69
	Multi-sensor	0.19	0.05		0.32	0.13	
2046	SCAN	0.14	0.03	0.55	0.26	0.09	0.63
	Multi-sensor	0.16	0.03		0.29	0.10	
2084	SCAN	0.14	0.03	0.59	0.38	0.17	0.69
	Multi-sensor	0.22	0.07		0.35	0.15	
2034	SCAN	0.16	0.04	0.50	0.33	0.14	0.59
	Multi-sensor	0.22	0.06		0.37	0.15	
2035	SCAN	0.15	0.03	0.55	0.28	0.10	0.66
	Multi-sensor	0.19	0.05		0.32	0.11	
2070	SCAN	0.16	0.04	0.56	0.31	0.12	0.69
	Multi-sensor	0.21	0.06		0.32	0.12	
2032	SCAN	0.12	0.02	0.56	0.31	0.11	0.67
	Multi-sensor	0.21	0.05		0.32	0.11	
2086	SCAN	0.01	0.00	0.56	0.23	0.07	0.72
	Multi-sensor	0.18	0.05		0.20	0.05	
2087	SCAN	0.00	0.00	0.48	0.29	0.10	0.72
	Multi-sensor	0.09	0.01		0.24	0.07	

Table 2. Difference (multi-sensor – SCAN), ratio (multi-sensor / SCAN), and percent difference ([multi-sensor – SCAN] / multi-sensor) values for mean daily precipitation estimates from multi-sensor and SCAN data. [From Dyer (2008)]

	All Values		Warm Season		Cool Season	
All precipitation values						
SCAN ID	Difference	% Diff	Difference	% Diff	Difference	% Diff
2091	-0.03	-0.49	-1.09	-0.83	1.19	-0.11
2046	0.60	-0.34	1.46	-0.08	0.13	-0.64
2084	-0.34	-0.05	-1.00	-0.02	0.16	-0.08
2034	1.39	-0.33	1.52	-0.22	0.03	-1.28
2035	1.23	-0.23	3.04	-0.06	-0.66	-0.41
2070	0.11	-0.21	1.33	0.00	-0.98	-0.40
2032	-0.47	-1.06	0.32	-1.30	-1.17	-0.84
2086	0.39	-0.35	0.67	-0.34	0.13	-0.35
2087	-0.09	-0.35	-0.95	-0.49	0.23	-0.26
Precipitation values where associated multi-sensor estimate is > 25 mm						
SCAN ID	Difference	% Diff	Difference	% Diff	Difference	% Diff
2091	2.34	0.04	-2.37	-0.07	5.38	0.10
2046	3.38	0.11	4.89	0.15	1.92	0.08
2084	-1.04	-0.07	-5.82	-0.22	1.61	0.01
2034	9.25	0.18	7.94	0.19	7.83	0.14
2035	-0.11	-0.04	8.86	0.21	0.09	0.03
2070	2.61	0.08	4.94	0.10	0.96	0.05
2032	2.19	0.03	3.91	0.07	0.86	0.00
2086	3.82	0.10	7.57	0.10	2.47	0.10
2087	3.77	0.05	7.01	0.08	2.05	0.01

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6. Information Transfer and Dissemination

The results of the research conducted during the course of this project have been disseminated through peer-reviewed publications and conference presentations. The results from the primary objective are included in a manuscript that is currently under review in *Water Resources Research* (Dyer, 2009a). Additionally, early findings were presented at the 103rd annual meeting of the Association of American Geographers (Dyer, 2007a), while final results were presented at the 23rd Conference on Hydrology at the annual meeting of the American Meteorological Society (Dyer, 2009b).

The results from the secondary objective are included in a manuscript that has been published in *Physical Geography* (Dyer, 2008). Preliminary results were also presented at the 10th annual meeting of the International Geographical Union (Dyer, 2007b).

Final results of the project, including conclusions from both project objectives, will be presented at the Mississippi Water Resources Conference in August.

7. Student Training

A research assistant, Heather Hyre, was funded during Fall semester 2008 through this project, housed in the Department of Geosciences. Ms. Hyre is a first year master's student studying operational/applied meteorology, and although she is not pursuing a thesis in direct association with this project, she is utilizing the associated data and methods to investigate precipitation distribution and related surface influences at locations in the northeast US.

8. Financial Summary

Initial budget for funded project:

Cost Category		Percent Time Devoted to Project	Total Salary	Federal Contribution	State Contribution	Matching Contribution	Total
1. Salaries and Wages	PI	15%	$51,665	$3,875	$3,575	$0	$7,450
	GRA	50%	$12,000	$3,000	$3,000	$0	$6,000
	Total			$6,875	$6,575	$0	$13,450
2. Fringe Benefits				$1,301	$1,202	$0	$2,503
3. Supplies				$140	$140	$0	$280
4. Permanent Equipment				$600	$600	$0	$1,200
5. Travel				$1,510	$987	$0	$2,497
6. Other Direct Costs				$2,232	$2,232	$20,000	$24,465
Total Direct Costs				$12,658	$11,737	$20,000	$44,394
8. Indirect Costs				$0	$0	$8,914	$8,914
9. Total Estimated Costs				$12,658	$11,737	$28,914	$53,308

Expenditures during quarterly reporting periods:

1st quarter [3/1/2008 – 6/30/2008]:

Federal: $0.00, Non-Federal: $0.00, Cost Share: $0.00

2nd quarter [7/1/2008 – 9/30/2008]:

Federal: $1,306.80, Non-Federal: $2,180.07, Cost Share: $0.00

3rd quarter [10/1/2008 – 12/31/2008]:

Federal: $1265.25, Non-Federal: $1265.25, Cost Share: $0.00

4th quarter [1/1/2009 – 2/28/2009]:

Federal: $9,510.73, Non-Federal: $8,305.56, Cost Share: $20,000.00