1.1 EVALUATION AND APPLICATIONS OF NCEP STAGE II AND STAGE IV GAGE-CORRECTED RADAR PRECIPITATION ESTIMATES OVER THE CAROLINAS

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1. INTRODUCTION

The National Centers for Environmental Prediction have created national mosaics of radar precipitation estimates calibrated with surface gage observations. These gridded products provide hourly and 6-hourly precipitation estimates on ~5km grid using Multi-sensor Precipitation Estimates (MPE) algorithms used by the NWS River Forecast Centers. Such high-resolution gridded precipitation estimates could be valuable for many hydrological applications, such as drought monitoring, irrigation scheduling, and mesoscale precipitation research.

As described by Lin and Mitchell (2005), NCEP Stage II estimates combine radar precipitation estimates with hourly observations from operationally available surface gages (e.g. ASOS), accounting for general bias in the radar returns. Stage II estimates are quickly available and effective for precipitation monitoring. Stage IV (also referred to as MPE) precipitation estimates, with an added human quality control aspect, are generally more accurate and therefore valuable in monitoring and research applications. However, Stage IV products are not as rapidly available for dissemination.

Several recent studies specifically investigate the accuracy of gage-corrected radar estimates produced by National Weather Service, including Wang et al. (2000) and Marzen and Fuelberg (2005). However, none have specifically investigated the accuracy of NCEP precipitation estimates over areas with diverse topographic regimes. The Carolinas region of the southeastern United States contains a wide range of topographic regimes, including the relatively flat coastal plains in the east, rolling hills in the central Piedmont region, and the highest peaks in the eastern United States (>2000 meters) along the southern Appalachians. This region provides a more robust test for the Stage II and Stage IV precipitation estimates.

The NCEP Stage II and Stage IV precipitation estimates are evaluated over the Carolinas for accuracy at several time scales. NWS Cooperative observer gages, which are not included in the MPE estimation process, are used in this analysis as independent surface precipitation observations to verify the NCEP gridded radar estimates. Comparative statistics and confidence intervals are calculated for the region based on errors at daily time scales for each season. Two applications of the gage-corrected radar estimate products are discussed and evaluated: (1) development of a heavy precipitation mapping and alert system for storm water quality management, and (2) mesoscale precipitation climatology research.

2. EVALUATION OF STAGE II & STAGE IV ESTIMATES

Daily precipitation observations reported by NWS Cooperative (Coop) observer gages are compared to the NCEP Stage II and Stage IV estimates for the period 2002-2004 over the southeastern United States including North Carolina and South Carolina. The study area, with locations of the NWS Coop gages and WSR-88D radar sites, is shown in Figure 1. Data for 2002-2004 are used since Stage IV precipitation estimates are only available since 2002 for this region (Stage II estimates are available since mid-1996). Since 24-hour NCEP estimates precipitation products are available at 1200Z, only Coop gages with time of observation between 0600 and 0900 local time are used in the comparison (equate to 1000Z -1400Z). Coop stations with time of observation in the late afternoon or midnight local time are ignored. There are 485 AM reporting stations used in this study.

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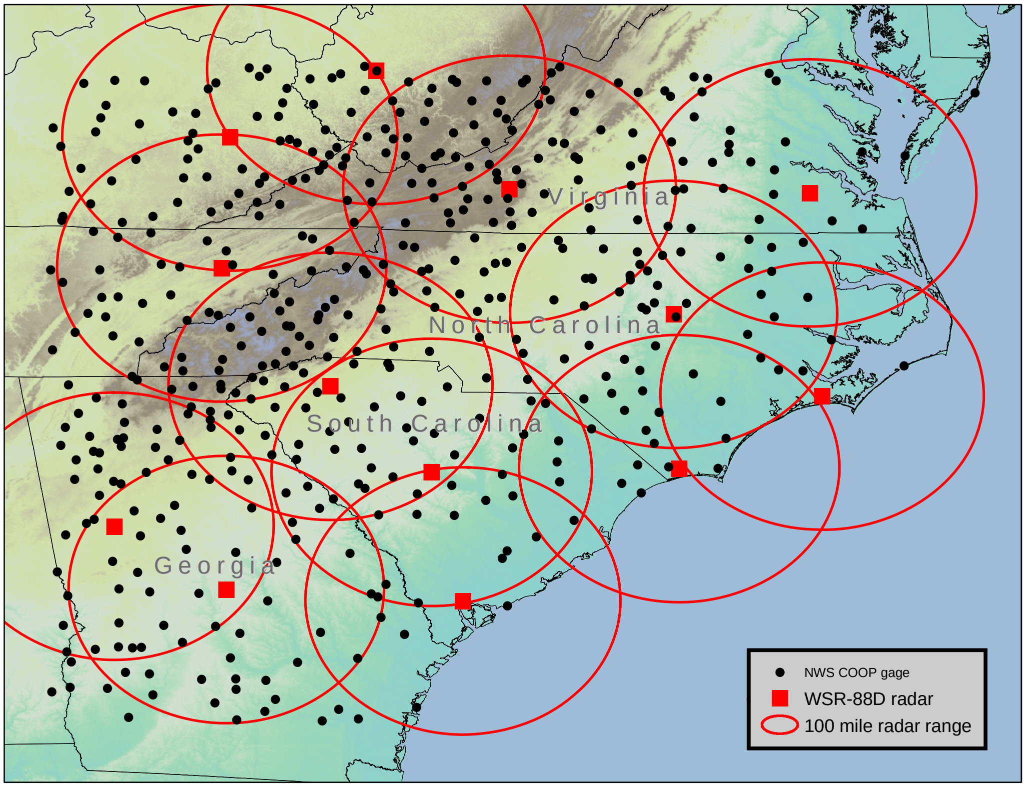

Fig 1. Study area with locations of 485 NWS Cooperative Observer gages and WSR-88D radar sites in the study area over the Carolinas. Radar coverage areas are drawn at 100 miles from each radar site.

Table 1 summarizes the statistics comparing the Stage II and Stage IV precipitation estimates with observed amounts from Coop gages, including Root Mean Squared Error (RMSE), Bias, Absolute Bias, Pearson Correlation, Index of Agreement (IOA), Variance of the Bias, and the Inter-Quartile Range (IQR) of the Bias during precipitation events. The IQR is calculated based on the bias only associated with precipitation events to eliminate any influence associated with days without observed precipitation. Table 2 shows the differences between Stage II and Stage IV statistics.

NCEP Estimate	Season	Mean RMSE	Mean Bias	Mean Absolute Bias	Mean Correlation	Mean Index of Agreement	Mean Variance of the Bias	Mean IQR of the Bias
Stage IV	Winter	0.019	-0.020	0.064	0.815	0.806	0.038	0.181
Stage II	Winter	0.023	-0.040	0.080	0.725	0.697	0.050	0.169
Stage IV	Spring	0.021	-0.009	0.076	0.832	0.829	0.049	0.175
Stage II	Spring	0.028	-0.027	0.098	0.765	0.752	0.066	0.162
Stage IV	Summer	0.028	0.001	0.108	0.766	0.762	0.082	0.202
Stage II	Summer	0.033	-0.018	0.134	0.667	0.657	0.104	0.183
Stage IV	Fall	0.023	-0.021	0.075	0.860	0.855	0.066	0.182
Stage II	Fall	0.028	-0.039	0.095	0.777	0.761	0.089	0.146
Stage IV	Annual	0.023	-0.012	0.081	0.818	0.813	0.059	0.185
Stage II	Annual	0.028	-0.031	0.101	0.733	0.717	0.077	0.165

Table 1. Summary statistics comparing NCEP Stage IV and Stage II daily precipitation estimates with observations from 485 NWS Cooperative observer gages for the period 2002-2004.

Season	Mean RMSE	Mean Bias	Mean Absolute Bias	Mean Correlation	Mean Index of Agreement	Mean Variance of the Bias	Mean IQR of the Bias
Winter	-0.004	0.020	-0.015	0.090	0.110	-0.012	0.012
Spring	-0.007	0.018	-0.022	0.067	0.077	-0.017	0.013
Summer	-0.005	0.018	-0.026	0.099	0.105	-0.021	0.019
Fall	-0.005	0.017	-0.020	0.083	0.094	-0.022	0.035
Annual	-0.005	0.018	-0.021	0.085	0.096	-0.018	0.020

Table 2. Difference between Stage IV and Stage II summary statistics as detailed in Table 1. Values represent Stage IV minus Stage II for each statistic.

Based on these statistics comparing Coop gage observations with NCEP estimates, a few general conclusions are derived. First, both Stage II and Stage IV estimates compare well with observations. Second, overall accuracy as measured by RMSE, absolute bias, and correlation, is highest during the winter season and lowest during the summer months. This result seems intuitive, given the convective nature of summer storms in this region. Finally, Stage IV precipitation estimates are generally more accurate than Stage II. By every statistical measure used here, the human-quality control added as part of the MPE process improves the accuracy of the estimates in each season.

Dot-plots of two comparative statistics (RMSE, IOA) for Stage IV estimates are provided in Figures 2-4 to show the spatial variation of these comparative measures. Figure 2 shows the spatial variation of RMSE and Figure 3 shows the variation of Index of Agreement. Figure 4 depicts the spatial variation of mean annual bias.

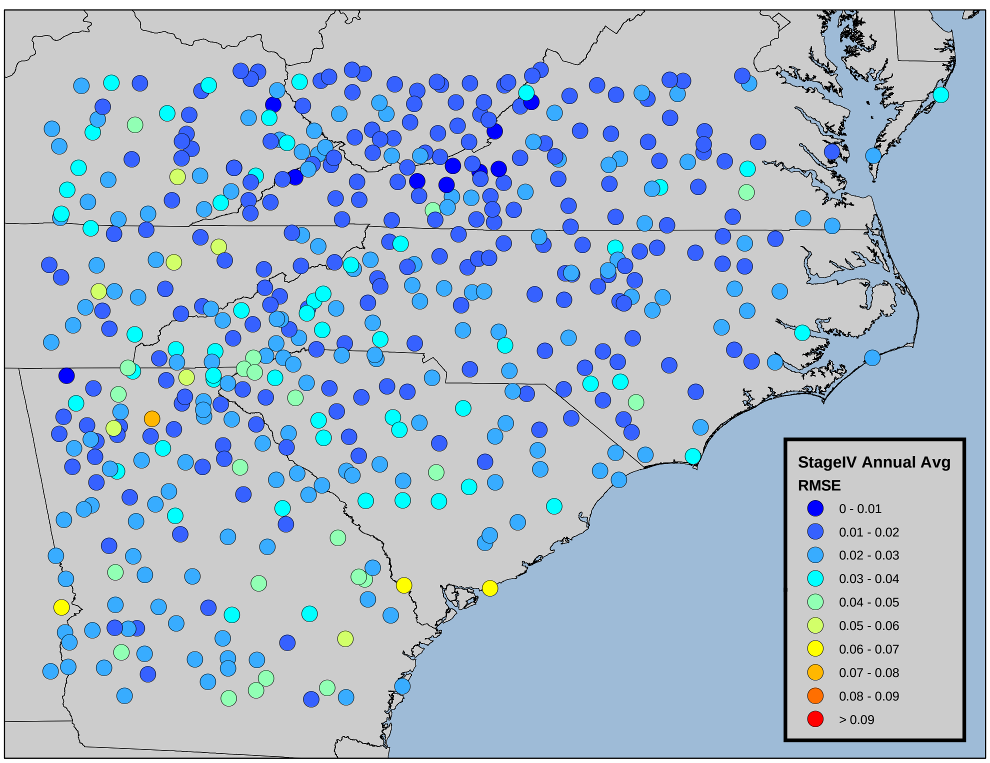

Fig 2. Spatial variation of annual average RMSE for Stage IV precipitation estimates as compared with NWS Cooperative observer gages. RMSE is given in Inches.

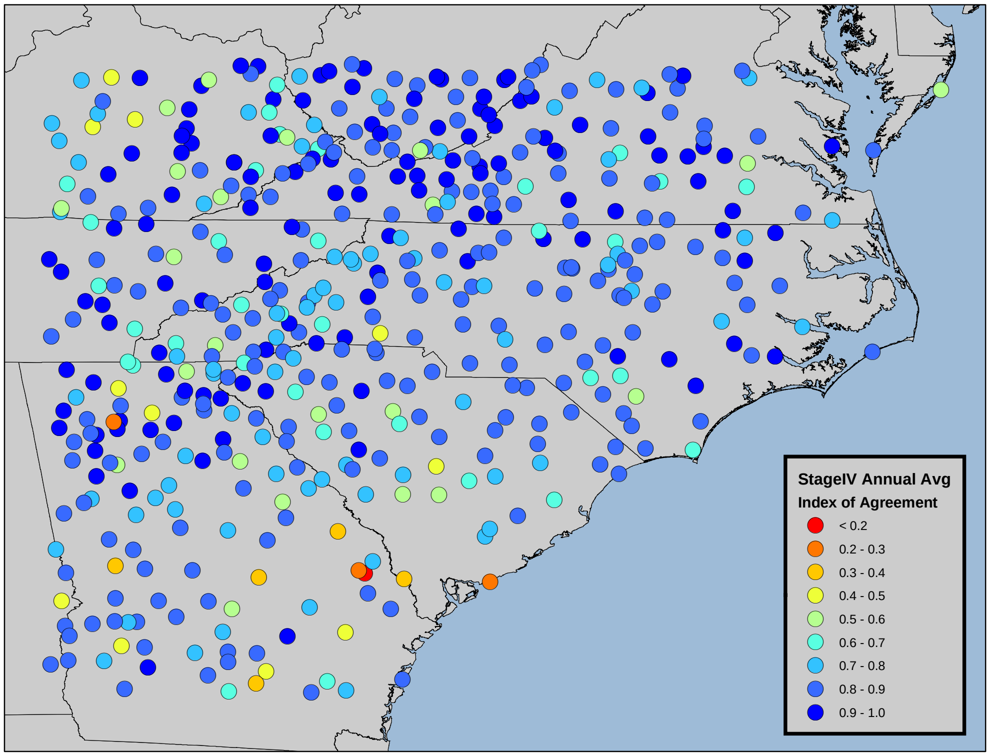

Fig 3. Spatial variation of annual average Index of Agreement between Stage IV precipitation estimates and NWS Cooperative observer gages.

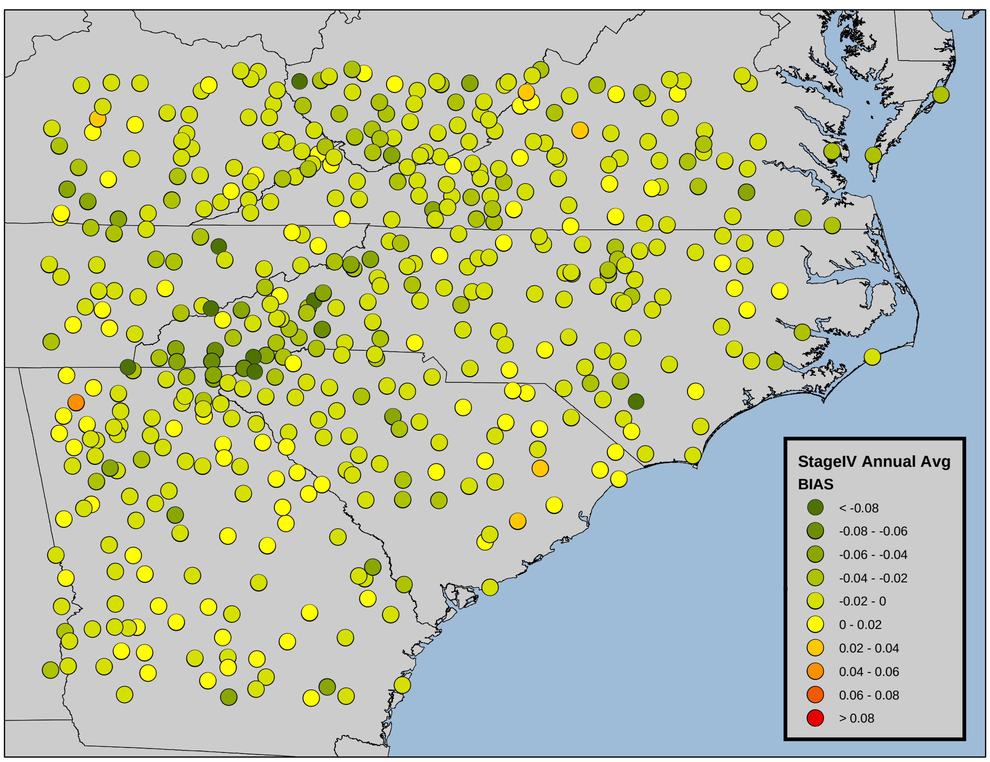

Fig 4. Spatial variation of annual average Mean Bias for Stage IV precipitation estimates as compared with NWS Cooperative observer gages. Mean bias is given in inches.

Analysis of the spatial variation of these statistics provides useful insight into regional errors associated with the Stage IV estimates. Root mean squared error (RMSE) values as seen in Figure 2 are generally low (<0.03 inches) across the region, with higher values observed in the southern mountains of North Carolina and the eastern coastal plain of South Carolina and Georgia. RMSE values are generally highest in the summer (figure not shown) and are more concentrated in eastern South Carolina and Georgia during the summer. These higher values are generally expected given the highly localized convection that typically occurs in this region during summer months. Also, there are scattered sites with high RMSE values are in eastern SC and GA where WSR-88D radars are in close proximity (figure not shown). RMSE values are also relatively high during the fall season (figure not shown), especially along the eastern side of the Appalachian Mountains. The impact of tropical cyclones is a likely source of error in this region, especially in 2004 when several tropical storms affected the area region with record-setting rainfall amounts.

A few isolated sites with high RMSE values are observed where nearby sites show low error. More research is needed to identify the reasons for such localized error and determine if problems lie with the radar estimates or Coop gage observations.

The spatial variation of Index of Agreement (IOA) is shown in Figure 3. IOA values are generally high, with most of the study area showing values greater than 0.8. This suggests that the temporal pattern of rainfall intensity is well-captured by the Stage IV precipitation estimates in all seasons. However, a few isolated locations show low IOA values. The reason for this is unknown, and will require further investigation.

The spatial patterns of annual average mean bias, as shown in Figure 4, suggest that bias is generally zero +/- 0.02 inches. As a general rule, the bias is more negative in the southern mountains of NC and SC. This is likely due to radar beam blocking – the WSR-88D that serves this local area in Greer, SC is sited at a much lower elevation. Therefore, the radar beam is blocked and unable to provide a more accurate estimate. It should also be noted that this area in the southern Appalachians is climatologically the wettest in the study region, with annual normal precipitation in excess of 80 inches. While mean bias is generally near zero or slightly negative, positive biases are larger and more widespread during the summer season (figure not shown). Again, this result is intuitive given the locally convective nature of precipitation during this season.

Overall, statistical analysis suggests that Stage IV precipitation estimates compare well with observations, especially over North Carolina and Virginia. Errors generally increase in the coastal plains of South Carolina and Georgia. Based on this comparison of NCEP estimates with observations from the NWS Coop network, Stage IV products are likely of sufficient accuracy for a wide range of applications, including drought monitoring, mesoscale research, and decision support tools. Two applications of the NCEP precipitation estimates are described below.

3. APPLICATIONS OF NCEP ESTIMATES

3.1 Heavy Precipitation Alert System

The State Climate Office of North Carolina (SCO) has developed an alert system for the NC Department of Transportation (NCDOT) to notify regional engineers when heavy precipitation falls over a highway construction zone. For these purposes, heavy precipitation is defined as > 0.5 inches over a 24 hour period. For all highway construction zones, NCDOT must take storm water control measures during heavy precipitation events to prevent runoff of soil into local streams. NCDOT originally contacted the SCO to install and maintain rain gages at each work zone. However, with dozens of work areas in the NC on any given month that change from week to week, a network of portable automated gages did not seem cost effective. Instead, the SCO used the Stage IV estimates to provide local rainfall estimates and to alert regional NCDOT engineers when heavy precipitation has occurred of a specific area of interest. Errors associated with each estimate are derived from the summary statistics described above and provided with each observation. A website developed at the SCO provides NCDOT users with an interface to view estimates from specific sites and set warning thresholds for each work zone of interest. This alert system is a useful application of the NCEP Stage IV precipitation estimates and highlights the value of such products over both gage networks and radar estimates alone.

3.2 Mesoscale Precipitation Research

The SCO is also involved in research to improve understanding of local and mesoscale forces on precipitation development. While the NWS Coop observations provide sufficient spatial and temporal resolutions for synoptic-scale research, NCEP gage-corrected precipitation estimates provide, for the first time, a longer record of data that has high spatial density (~ 5 km) and high temporal density (hourly estimates). NCEP Stage II and Stage IV products are being used to better resolve the influence of local topography on precipitation in the southern Appalachians and the identify the contribution of sea-breeze circulations to the overall climate of the coastal plains in North Carolina. Previous research by Gilliam et al. (2004) suggests that sea breeze convection will be enhanced over Cape Fear and Cape Lookout in North Carolina due to the shape of the coastline. NCEP gage-corrected precipitation estimates are being used to better identify these focus zone where NWS Cooperative observer gages do not exist at the needed spatial density. Similarly, research by Raman et al. (2005) suggests that a zone in central North Carolina known as the Sandhills with dramatic changes in soil type causes a local thermal circulation (similar to sea-breeze) that may also contribute to observed increases in precipitation over this region. Again, NCEP gage-corrected precipitation estimates are being used to research the locally-forced circulations in this region where surface gage networks lack the needed spatial density.

4. SUMMARY

NCEP Stage II and Stage IV gage-corrected radar precipitation estimates are compared with observations from 485 National Weather Service Cooperative observer gages in the Carolinas. As measured by several comparative statistics, Stage II and Stage IV products estimating observed precipitation on daily time scales compare well with observations. Comparative statistics are better with Stage IV than Stage II products and are of sufficient accuracy to be useful in a wide range of applications.

A heavy precipitation alert system has been developed at the State Climate Office of North Carolina to notify regional transportation engineers and construction managers when heavy precipitation falls over a construction zone. Using NCEP Stage II and Stage IV estimates, this application allows storm-water runoff control measures to be implemented as needed and is more cost effective as compared to a high density mobile rain gage network.

NCEP Stage II and IV products are also being used by the SCO to investigate mesoscale precipitation patterns in coastal, central and mountainous regions of North Carolina. The spatial and temporal density of the NCEP estimates is much higher than the available surface gage networks and allows for research into local meteorological processes not previously possible.

5. ACKNOWLEDGEMENTS

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