Projections of Extreme Rainfall for Georgia's 11 Near-Coastal Counties

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Objective: This project extended our analysis to 11 coastal Georgia counties* of 50-year, 24-hour return levels of precipitation, along with uncertainty ranges, that we previously derived for Liberty County, Georgia, for the late 21st century. We employed the Generalized Extreme Value methodology to create the 50-year, 24-hour return levels on a high-resolution gridded dataset for historical (1961-2000) and projected future (2081-2100) time periods, using both a lower-end [representative concentration pathway 4.5 (RCP4.5)] and high-end (RCP8.5) future greenhouse gas emissions scenario. Our analysis utilized an updated version of the University of Wisconsin-Madison Probabilistic Downscaling (UWPD) product, which contains statistically downscaled data of global climate models (GCMs) in the CMIP5 archive.

**Counties: Brantley, Bryan, Camden, Charlton, Chatham, Effingham, Glynn, Liberty, Long, Mcintosh, and Wayne*

Observational Datasets:

National Oceanic and Atmospheric Administration (NOAA) Atlas 14, Volume 9, Version 2 (Perica et al. 2013)

Climate Model Datasets:

University of Wisconsin-Madison Probabilistic Downscaling (UWPD)
-- 22 GCMs from the Coupled Model Intercomparison Project Phase Five (CMIP5) archive (see Table 1)
-- Grid resolution of downscaled product: 0.1° latitude x 0.1° longitude
-- Historical (1961-2000) and late-21st century (2081-2100) time periods
-- Greenhouse gas emissions scenarios: RCP4.5 (lower-end) and RCP8.5 (high-end)
-- Probability density functions of expected annual maximum daily precipitation were used to construct estimates of the 50-year, 24-hour return levels.
-- UWPD references: WICCI 2011; Notaro et al. 2014; Vavrus et al. 2015; Kirchmeier-Young et al. 2016 (dataset developer: David Lorenz)

Methodology:

Observed estimates of the 50-year (average recurrence interval), 24-hour (duration) precipitation for the Southeast United States were downloaded from the very high-resolution NOAA Atlas 14 grid in netcdf format. Shapefiles were then created to analyze the 11 coastal Georgia counties (Figure 1). Based on our previous study of Liberty County, Georgia, we determined that the NOAA Atlas 14 extreme precipitation data virtually match historical precipitation records from weather stations and therefore may be reliably used to represent observations during the historical period.

For both the historical and future time periods, we utilized UWPD's expected annual daily maximum precipitation amount that is expressed as a probability density function (PDF) of possible values to account for stochastic weather variations. The PDF was used to generate 10,000 random realizations of annual daily maximum precipitation for every UWPD grid box within the 11 coastal Georgia counties. Generalized Extreme Value (GEV) theory (Coles 2001) was then applied to these synthetic annual daily maximum rainfall amounts, which were inflated by an empirically derived factor of 1.12 to convert from calendar day totals to expected totals over any 24-hour time span (Hershfield 1961, Perica et al. 2013). To translate these annual-maximum precipitation values to corresponding 50-year return levels, we used the National Center for Atmospheric Research (NCAR) Command Language (NCL). The NCL function "extval_mlegev" estimates the location (related to the mean of the distribution), scale (representative of the variance), and shape (representative of the tails) parameters for the GEV distribution using the maximum-likelihood estimation. According to GEV theory, the return level is computed as:

$$Return\ Level = \frac{Scale}{Shape}\left[Coeff^{-1*Shape} - 1\right] + Location$$

where $Coeff = -1 * log\left[1 - \frac{1}{50}\right]$.

The raw UWPD estimates of 50-year, 24-hour precipitation amounts derived from the GEV calculations compare favorably with observations from NOAA Atlas 14 (Figure 2), which range from 7.44 to 11.44 inches. In most locations, values of the multi-model mean fall within 1 inch of those from the atlas. Near-coastal amounts are biased low, while inland amounts show both positive and negative biases. On average across the 11 counties, the raw UWPD estimates are only 0.21 inch lower than the atlas values, with the largest mean bias of -0.84 inch in Camden County in the far southeast.

To obtain the most reliable future projections, we accounted for differences between the raw modeled and observed estimates through the "delta method" debiasing technique. The delta method consists of multiplying the observed value of 50-year, 24-hour rainfall at each grid box by the simulated percentage change between future and raw historical values from UWPD. For example, suppose a location during the late 20th century has an observed return level of 10.0 inches and a slightly underestimated modeled value from one of the UWPD GCMs of 9.0 inches. If the same GCM simulates a future return level of 12.0 inches (a 33% increase), then the debiased future estimate would be 10.0 inches x 1.33 = 13.33 inches.

<u>Results</u>:

The projected changes in 50-year, 24-hour rainfall across the domain for the late 21st century show increases *at all grid points* in both the RCP4.5 and RCP8.5 scenarios, based on the <u>median</u> response among the 22 climate models (Figure 3). The changes in the RCP4.5 scenario are relatively modest, averaging +0.55 inch and ranging spatially from as small as +0.14 inch to as much as +0.95 inches. The largest increases are seen in the central counties of Long, Liberty, and Mcintosh (averages=0.64, 0.63, and 0.65 inch, respectively), but overall there is no coherent pattern to the projected changes over the domain. Expressed in relative terms, the increases are also fairly small in RCP4.5 (overall average = 5.9%, maximum = 9.7%, minimum = 1.5%), with the largest areally averaged changes again in Long, Liberty, and Mcintosh Counties (7.6%, 6.8%, and 6.2%, respectively). A much larger response is simulated with the RCP8.5 greenhouse gas emissions scenario, with an average increase of 1.41 inches (15.3%) over the 11 counties that is more than double that of RCP4.5. The range of increases among grid cells is 0.95 to 1.89 inches, with the maximum in the northeastern counties. The smallest relative gains of as low as 8.7% are found in far-southeastern Camden County, while scattered increases of up to 21.0% occur. A gradient of percentage changes from smallest along the coast to largest inland is apparent in the RCP8.5 scenario but not in RCP4.5.

Mean or median projections among models are usually considered to be the best estimates of future changes, but they do not reflect potentially important differences in the responses *among models*. Therefore, a useful quantification of model uncertainty is the range of projections among models, as expressed by the smallest and largest simulated responses (Figure 4) and the corresponding 25th and 75th percentile values across the 22 climate models (Figure 5). For example, in both scenarios, the highest median-model return levels occur right along the coast, ranging from 11.5-12.5 inches in RCP4.5 and 12.0-13.0 inches in RCP8.5 (Figure 3), but individual models differ strongly in these estimates. Future return levels at these coastal locations vary across model from 7.0-15.6 inches in RCP4.5 and from 10.3-16.4 inches in RCP8.5 (Figure 4), thereby warranting caution in how precisely future conditions may be anticipated. Some of the extreme projections could be skewed by the debiasing method (in particular, models that vastly under-simulate precipitation extremes and thus require a large correction factor). Therefore, we recommend the 25th and 75th percentiles as a more conservative measure of model range. These narrower “bookends” show a similar spatial pattern but a muted range compared with the extremes (Figure 5) and are probably more justified as a plausible consensus measure of model uncertainty.

Taken together, the set of modeled medians, ranges, and extremes of 50-year, 24-hour return levels offer insights into both possible and likely future changes in extreme precipitation along near-coastal Georgia. A summary of these metrics is presented in Table 2 and Figure 6 using box-and-whiskers graphs of the area-averaged response across every county for the late 21st century in both greenhouse gas emissions scenarios. As expected, the highest return levels in both scenarios occur in the counties closest to the ocean (Glynn, Chatham, Mcintosh, and Camden), where the highest values also exist in the late 20th century (red dots). All of the counties show a future increase in the model-median values, but the rise is relatively modest in RCP4.5 (no more than 0.64 inch or 8% in any county), such that the modeled 25th-percentile future amount is approximately the same as the late-20th century benchmark. In every county, the RCP8.5 scenario leads to much higher projected return levels, in which the lowest simulated future amounts in any model are close to late-20th century conditions. The future return levels in all the counties under RCP8.5 are expected to increase by well over one inch (>10%).

<u>References</u>:

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Table 1. Names and institutions of the 22 global climate models used in this study.

Climate model	Institution
ACCESS1-0	Commonwealth Scientific and Industrial Research Organization (Australia)
ACCESS1-3	Commonwealth Scientific and Industrial Research Organization (Australia)
CMCC-CM	Centro Euro-Mediterraneo sui Cambiamenti Climatici Centre National de Recherches Météorologiques Centre (Italy)
CMCC-CMS	Centro Euro-Mediterraneo sui Cambiamenti Climatici Centre National de Recherches Météorologiques Centre (Italy)
CNRM-CM5	Centre National de Recherches Meteorologiques Scientifique (CNRM/France)
CSIRO-Mk3-6-0	Communication Scientific and Industrial Research Organization (CSIRO/Australia)
CanESM2	Canadian Centre for Climate Modeling and Analysis (CCCma/Canada)
GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory (GFDL/USA)
GFDL-ESM2G	NOAA Geophysical Fluid Dynamics Laboratory (GFDL/USA)
GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory (GFDL/USA)
HadGEM2-CC	United Kingdom Met Office Hadley Centre
IPSL-CM5A-LR	Institute Pierre-Simon Laplace (IPSL/France)
IPSL-CM5A-MR	Institute Pierre-Simon Laplace (IPSL/France)
IPSL-CM5B-LR	Institute Pierre-Simon Laplace (IPSL/France)
MIROC-ESM	Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
MIROC5	National Institute for Environmental Studies, The university of Tokyo (MIROC/Japan)
MPI-ESM-LR	Max Planck Institute for Meteorology (MPI-M/Germany)
MPI-ESM-MR	Max Planck Institute for Meteorology (MPI-M/Germany)
MRI-CGCM3	Meteorological Research Institute (MRI/Japan)
NorESM1-M	Norwegian Climate Centre (NCC/Norway)
inmcm4	Institute of Numerical Mathematics of the Russian Academy of Sciences

Table 2. *Area-averaged model medians, 25th/75th percentiles, and maximum/minimum values of 50-year, 24-hour return levels (inches) during the late 21st century for the RCP4.5 and RCP8.5 scenarios in all 11 counties. Also shown are the late 20th-century observed return levels and the simulated changes from these in each scenario.*

RCP4.5	Charlton	Wayne	Effingham	Brantley	Bryan	Long	Glynn	Chatham	Mcintosh	Liberty	Camden
Median	9.57	8.52	8.99	8.73	9.5	9.1	10.67	10.64	11.02	9.9	10.92
Minimum	8.1	7.23	7.62	7.2	8.33	7.94	8.35	9.27	9.46	8.7	7.93
Maximum	11.61	9.77	10.71	10.34	10.91	10.37	12.4	13.49	12.99	11.36	12.83
25th pctile	8.71	7.93	8.39	8.26	8.86	8.43	10.11	10.12	10.43	9.25	10.32
75th pctile	10.11	9.07	9.4	9.25	10.11	9.69	11.29	11.62	11.68	10.51	11.49
Late 20th Median	8.94	8.05	8.46	8.33	8.94	8.46	10.14	10.18	10.38	9.27	10.42
delta median (in.)	0.63	0.47	0.53	0.4	0.56	0.64	0.53	0.46	0.64	0.63	0.5
delta median (%)	7.0%	5.8%	6.3%	4.8%	6.3%	7.6%	5.2%	4.5%	6.2%	6.8%	4.8%
RCP8.5	Charlton	Wayne	Effingham	Brantley	Bryan	Long	Glynn	Chatham	Mcintosh	Liberty	Camden
Median	10.43	9.37	9.78	9.72	10.39	9.93	11.49	11.6	11.83	10.74	11.73
Minimum	8.94	8.07	8.27	8.32	8.79	8.57	10.04	10.02	10.52	9.21	10.05
Maximum	12.51	11.18	11.15	11.2	12.27	11.66	13.45	14.49	13.87	12.86	13.92
25th pctile	9.64	8.94	9.18	9.12	9.66	9.38	10.63	11	11.12	10.08	10.87
75th pctile	11	10.04	10.44	10.24	11.03	10.54	12.21	12.24	12.45	11.49	12.34
Late 20th Median	8.94	8.05	8.46	8.33	8.94	8.46	10.14	10.18	10.38	9.27	10.42
delta median (in.)	1.49	1.32	1.32	1.39	1.45	1.47	1.35	1.42	1.45	1.47	1.31
delta median (%)	16.7%	16.4%	15.6%	16.7%	16.2%	17.4%	13.3%	13.9%	14.0%	15.9%	12.6%

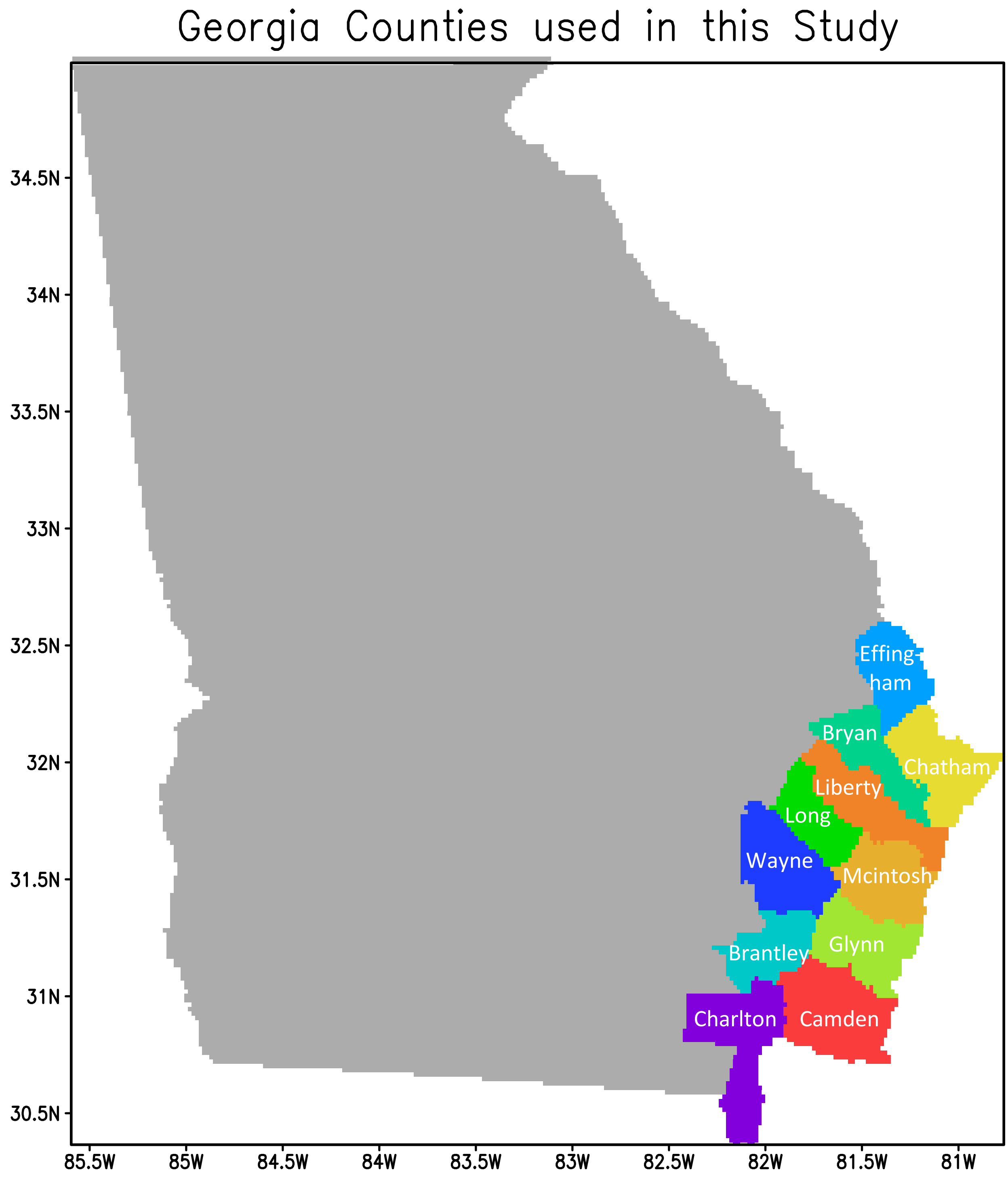

Figure 1. The 11 coastal counties of Georgia analyzed in this study.

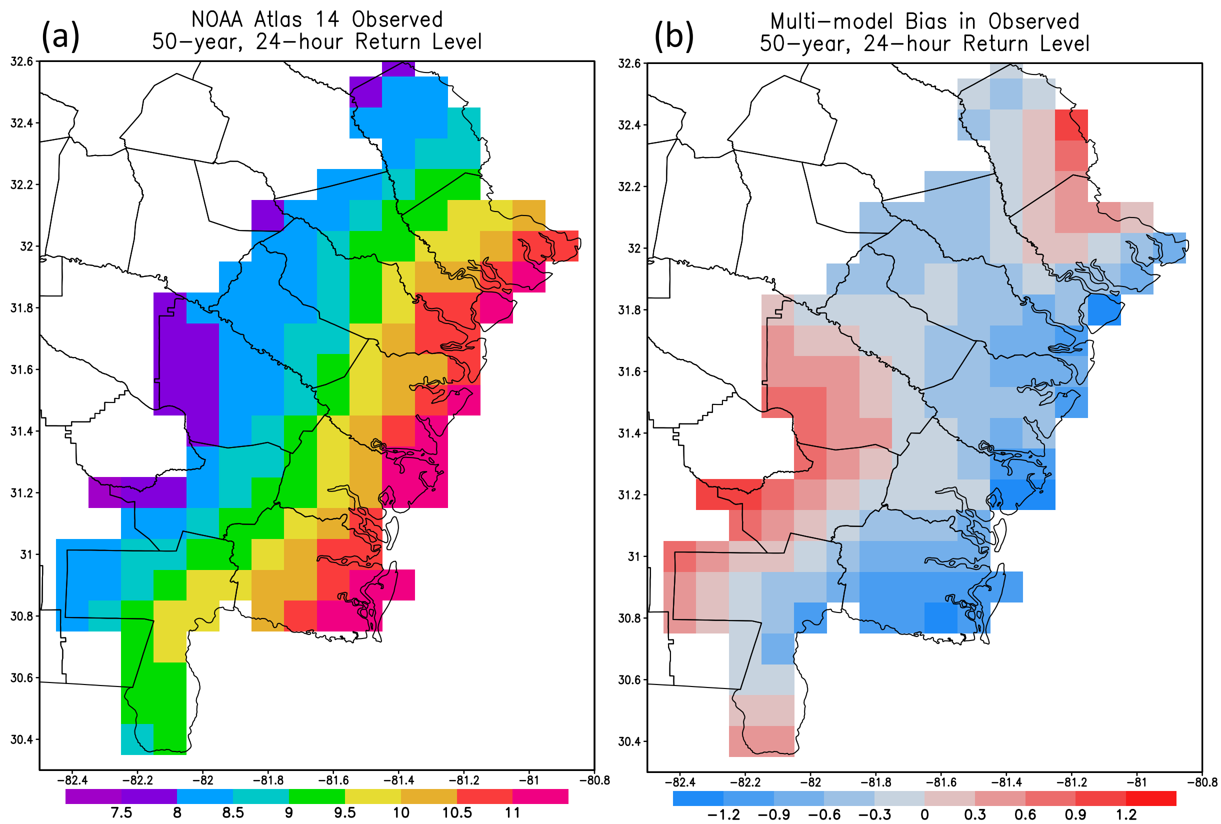

Figure 2. Observed return level (inches) of 50-year, 24-hour rainfall as (a) reported from NOAA Atlas 14, and (b) expressed as the bias of the downscaled multi-model mean simulation of all 22 GCMs.

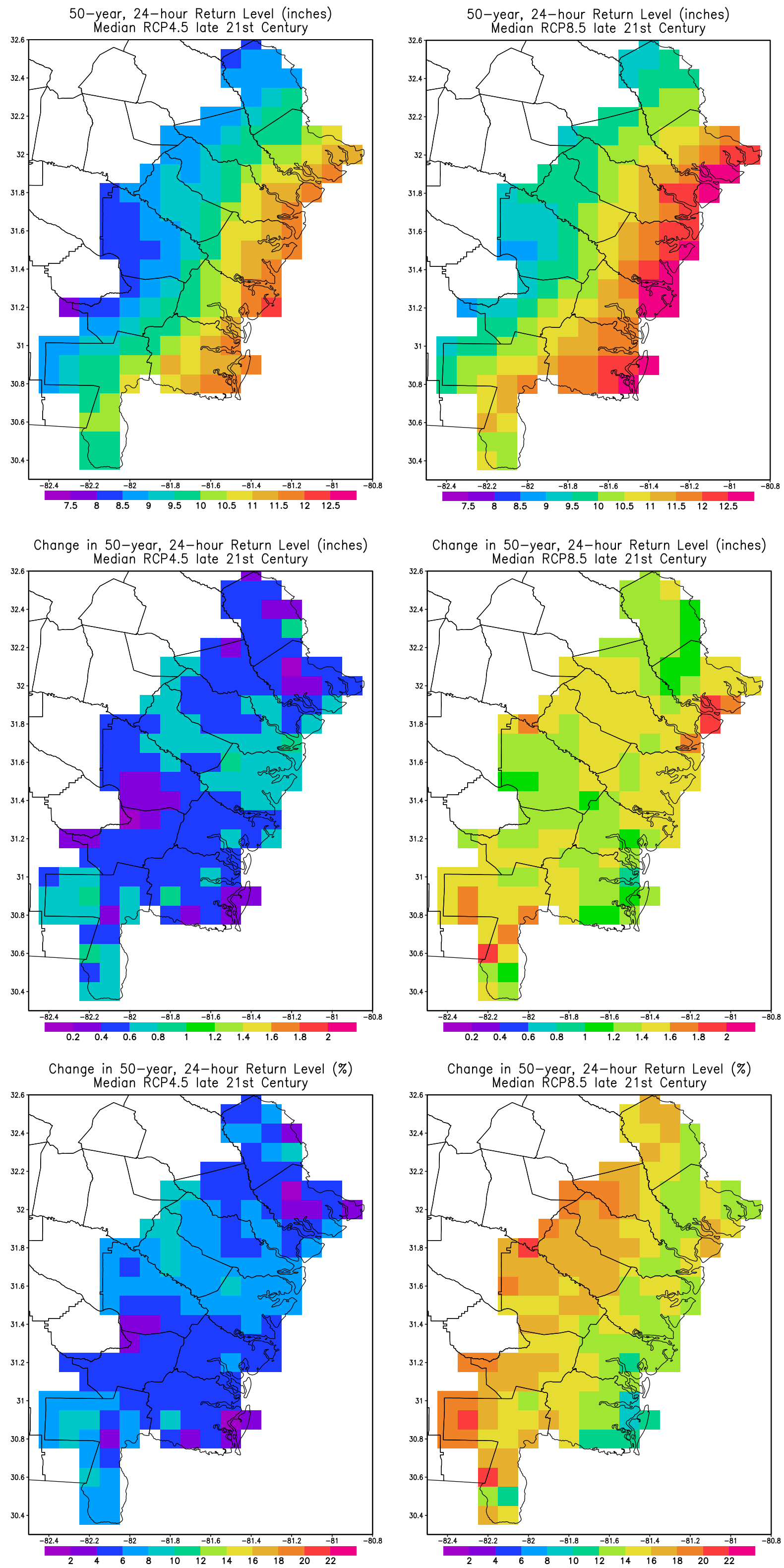

Figure 3. Multi-model median simulations of 50-year, 24-hour return level for (left) RCP4.5 and (right) RCP8.5 scenarios for the late 21st century. (top) Absolute value, (middle) change in absolute value from late 20th century, and (bottom) percentage change from late 20th century.

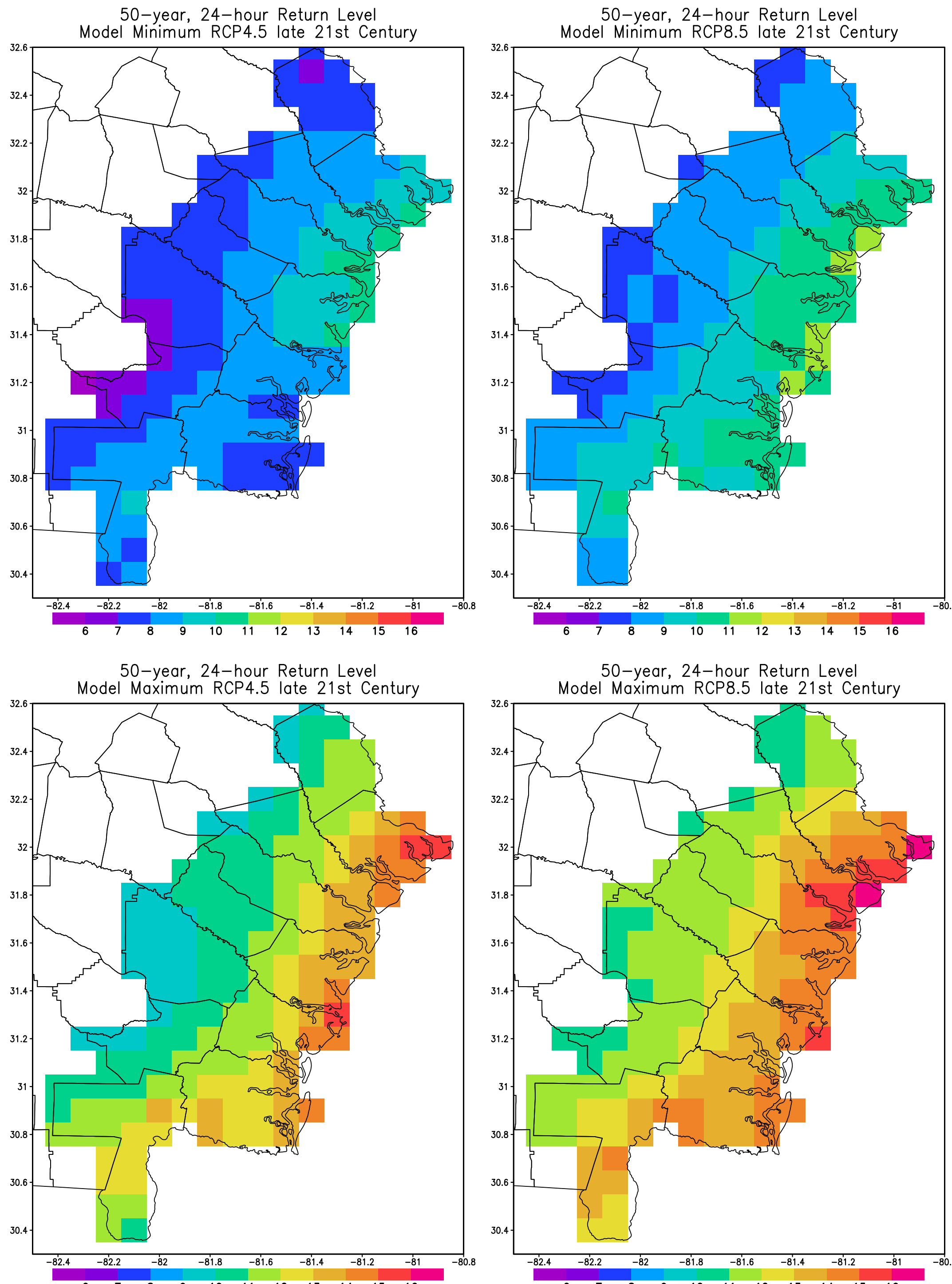

Figure 4. (top) Minimum and (bottom) maximum simulated values of 50-year, 24-hour return levels (inches) for late 21st century among the climate models for the (left) RCP4.5 and (right) RCP8.5 scenarios.

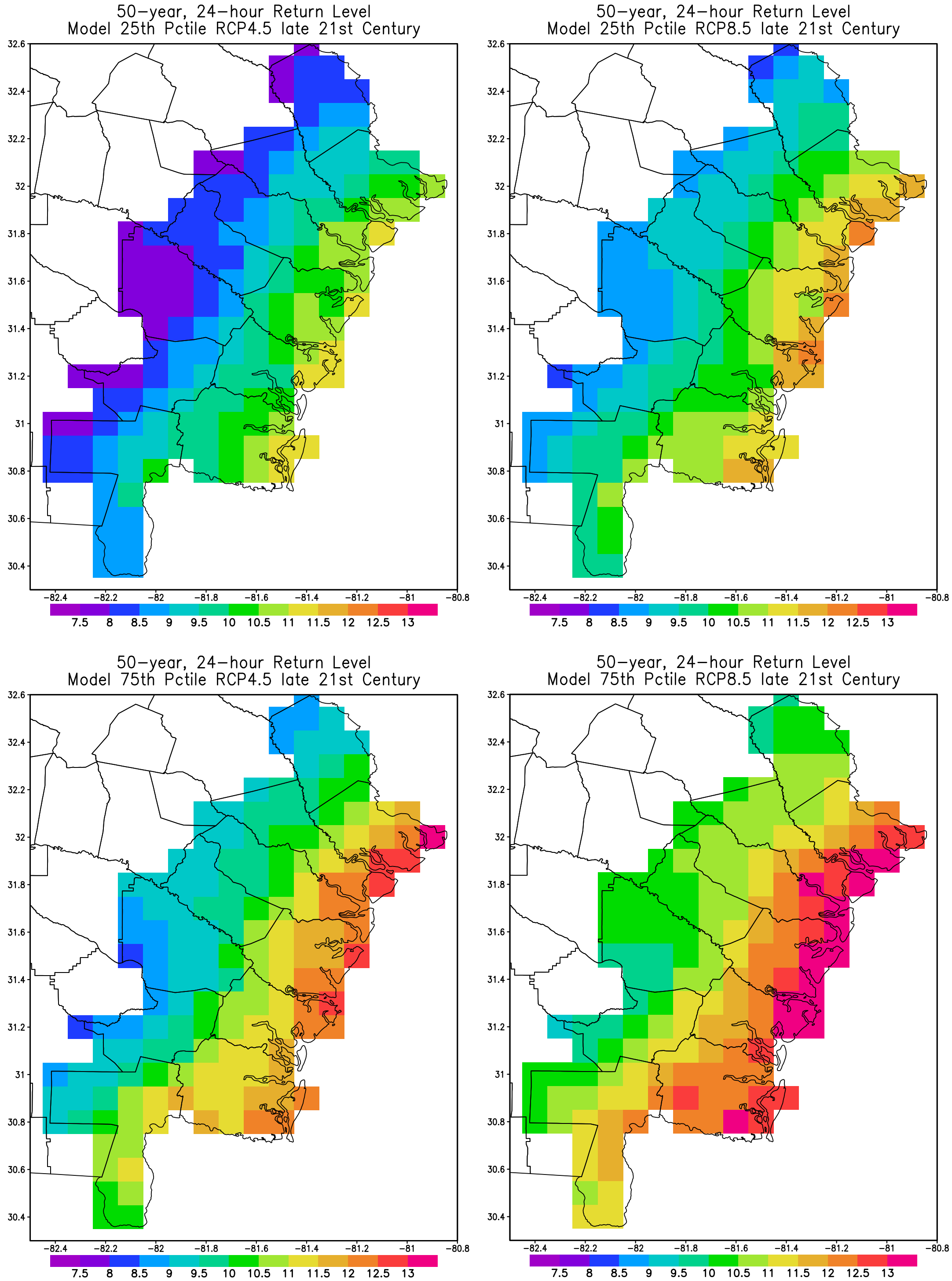

Figure 5. Same as in Figure 4 but for 25th and 75th percentile values among the models.

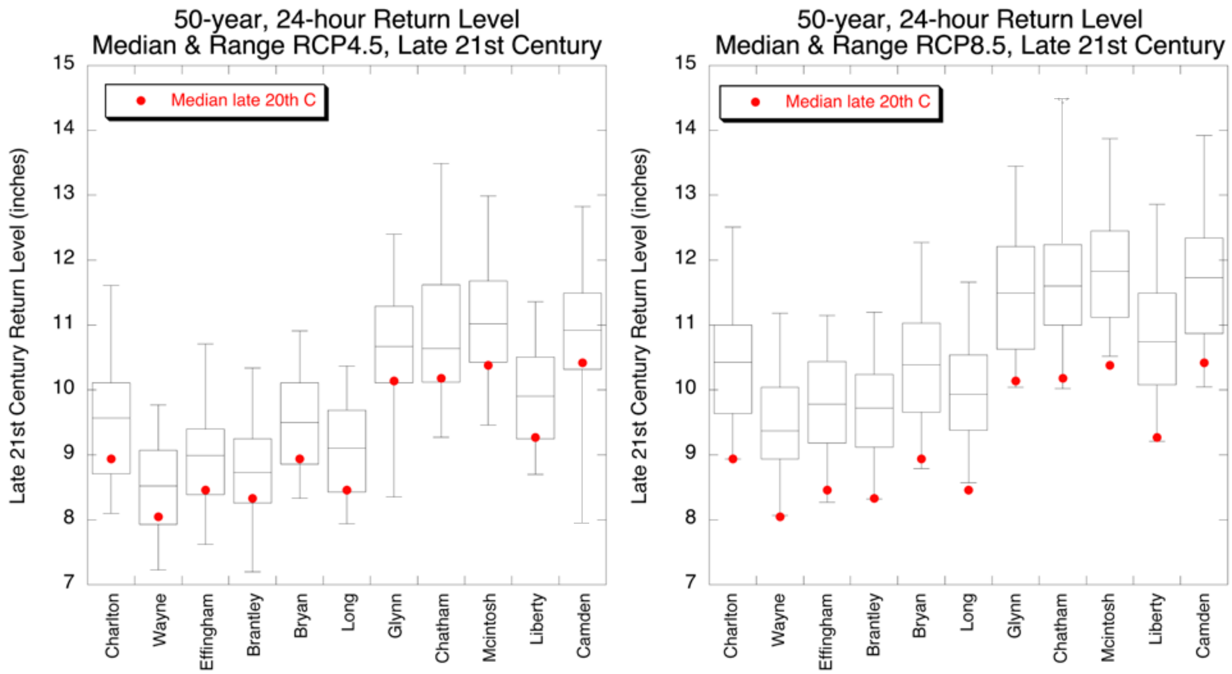

Figure 6. Area-averaged medians, 25th/75th percentiles, and maximum/minimum values of 50-year, 24-hour return levels for late 21st century for (left) RCP4.5 and (right) RCP8.5 scenarios in all 11 counties. The county median value in the late 20th century is shown in red dots for reference. Future median values are denoted by the horizontal line within each box, whose range encompasses the multi-model 25th to 75th percentiles. The maximum and minimum return levels simulated by any model are represented by the whiskers.