Potential changes in rainfall erosivity under climate change in southeastern United States

Bijoychandra Takhellambam[1]

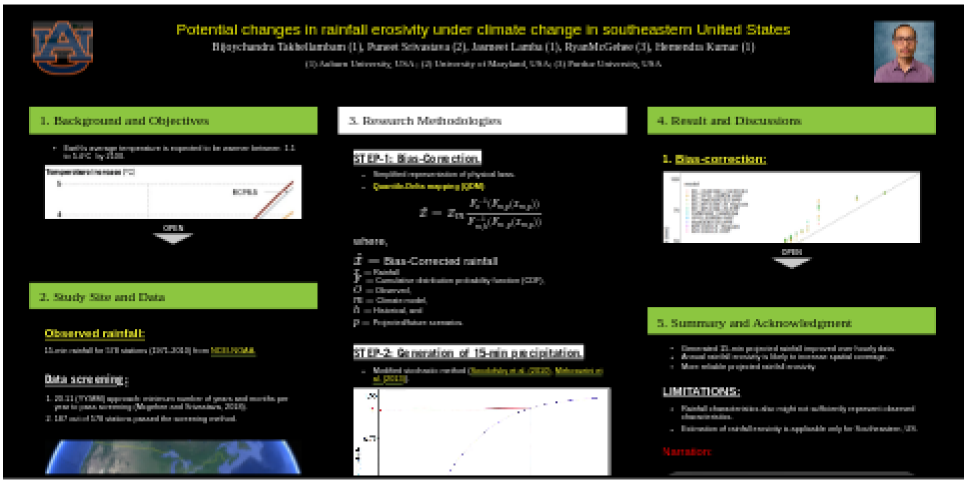
[1]Auburn University

November 22, 2022

Abstract

Climate change will amplify erosion rates as erosive power of rainfall will likely increase due to change in rainfall characteristics (e.g., energy, intensity, duration as well as frequency). According to Intergovernmental Panel on Climate Change Fourth Assessment report (IPCC AR4), it is projected that by mid-21st Century, the rainfall across southeastern US will both increase and decrease in intensity, which will substantially affect rainfall erosivity. Few studies have estimated the impact of climate change (e.g., rainfall intensity) on rainfall erosivity across US and around the world. However, previously published erosion indices have discrepancies due to differences in methodologies (e.g., primarily omission of small and low rainfall intensity) adopted in those studies. Therefore, the objective of this study was to estimate change in erosion indices for the period 2030-2059 using the benchmark rainfall indices established for southeastern region of US. Hourly precipitation data were retrieved from NA-CORDEX under Representative concentration pathways (RCP) 8.5. Results on change in erosion indices as a result of climate change will be presented.

Potential changes in rainfall erosivity under climate change in southeastern United States



Bijoychandra Takhellambam (1), Puneet Srivastava (2), Jasmeet Lamba (1), RyanMcGehee (3), Hemendra Kumar (1)

(1) Auburn University, USA ; (2) University of Maryland, USA; (3) Purdue University, USA

PRESENTED AT:

1. BACKGROUND AND OBJECTIVES

- Earth's average temperature is expected to be warmer between 1.1 to 5.4°C by 2100.

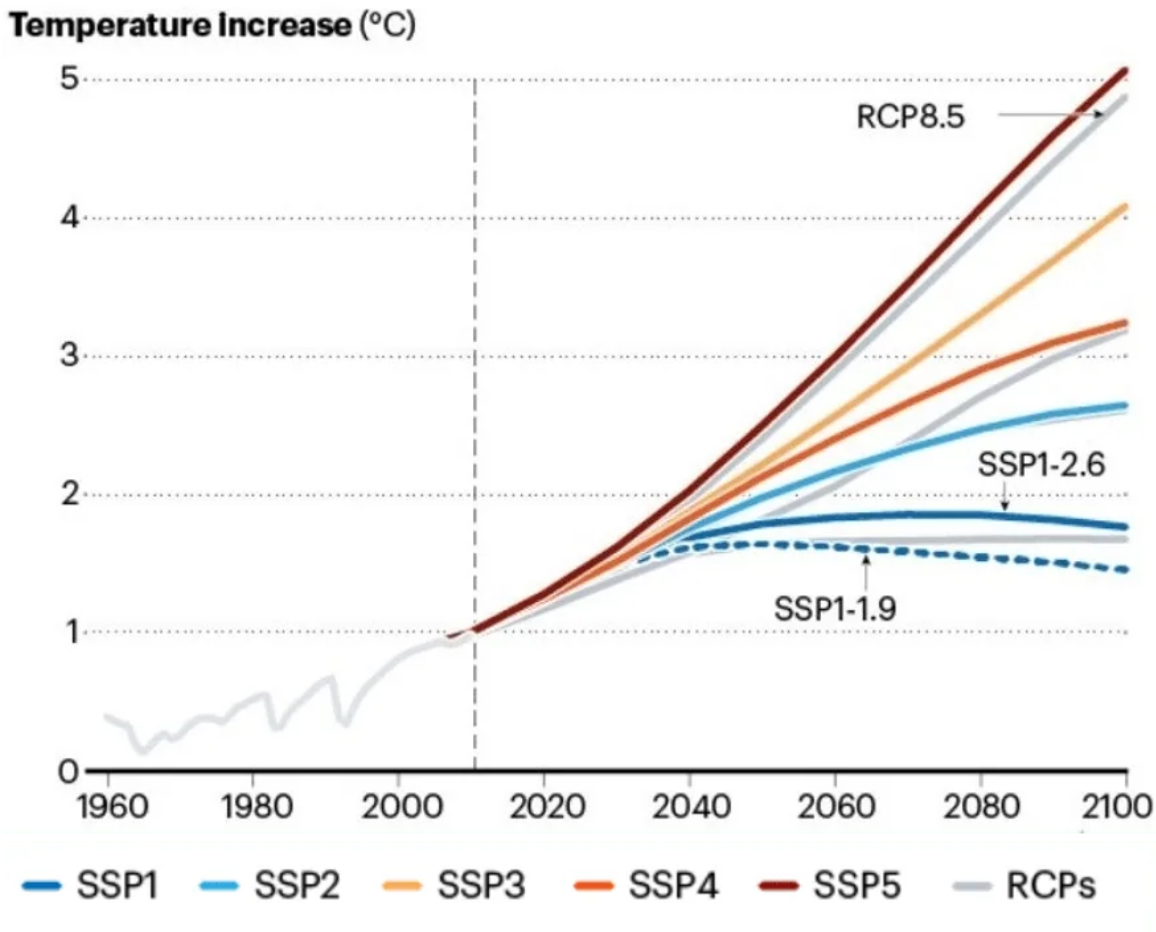


Fig 1: Projected temperature under different climate scenarios by 2100. Source: Jeff Tollefson (2020) (https://www.nature.com/articles/d41586-020-01125-x)

- Change in rainfall characteristics with climate change (e.g., Intensity, duration, and frequency).
  For example: According to the **Clausius-Clapeyron relation**, precipitation intensity can be increased by 6-7% per 1°C.

- Southeastern, US has the greatest potential impact on rainfall erosivity than other parts of the country with 2000 to >10,000 $(\frac{MJ.mm}{ha.h.yr})$.

- Need to quantify a reliable projected potential of rainfall to erode soil (Rainfall Erosivity, R).

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1638645506/agu-fm2021/2E-05-49-38-11-60-DA-D7-90-36-24-07-0E-0F-64-9F/Video/ParallelCandidAnteater_aufjm5.mp4
Fig 2: Soil erosion by water. Source: TheGoodKid (https://www.youtube.com/watch?v=N8C9OaBRW2g&fs=1&modestbranding=1&rel=0&showinfo=0)

Research Problems

1. Unavailability of high-resolution precipitation (daily rainfall led upto 30% under-prediction of R).

2. No reliable projected rainfall erosivity due to discrepancies in methodologies of previous studies

(e.g. limitation of rainfall intensity to 76 mm/h, omission of rainfall < 2.54 mm).

Solutions

1. Generation of 15-min precipitation using modified stochastic method.

2. Benchmarked reliable rainfall erosivity approach.

Narration:

2. STUDY SITE AND DATA

Observed rainfall:

15-min rainfall for 578 stations (1971-2010) from NCEI-NOAA. (http://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.ncdc:C00505)

Data screening:

1. 20.11 (YY.MM) approach: minimum number of years and months per year to pass screening (Mcgehee and Srivastava, 2018).

2. 187 out of 578 stations passed the screening method.

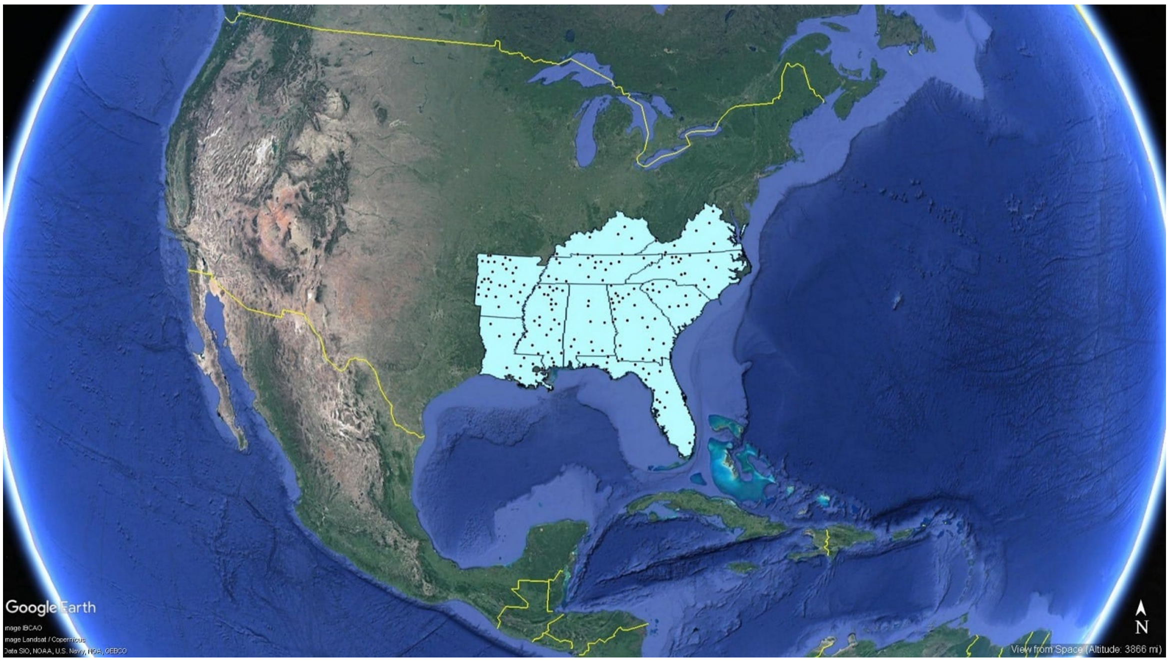


Fig 3: Locations of 187 observed precipitation stations after 20.11 screening.

Climate models:

Sl. No	Acronym	Regional climate model	Contributing institution
1	CANESM2_CANRCM4	Canadian Regional Climate Model version 4	Canadian Earth System Model
2	HadGEM2-ES.WRF	Weather Research and Forecasting	Hadley Centre Global Environment Model version 2 Earth system model
3	GFDL-ESM2M.WRF	Weather Research and Forecasting	Earth System Model – Geophysical Fluid Dynamics Laboratory
4	MPI-ESM-LR. RegCM4	Regional Climate Model version 4	Max Planck Institute for Meteorology Earth System Model LR
5	MPI-ESM-LR.WRF	Weather Research and Forecasting	Max Planck Institute for Meteorology Earth System Model LR

Table 1. Description of climate models from NA-CORDEX (https://www.earthsystemgrid.org/search/cordexsearch.html).

NOTE: Hist =1970-1999 , rcp8.5= 2030-2059, Precipitation frequency= 1 hour & spatial resolution=50 Km^2.

Narration:

3. RESEARCH METHODOLOGIES

STEP-1: Bias-Correction.

- Simplified representation of physical laws.

- **Quantile-Delta mapping (QDM)**:

$$\hat{x} = x_m \frac{F_o^{-1}(F_{m,p}(x_{m,p}))}{F_{m,h}^{-1}(F_{m,p}(x_{m,p}))}$$

where,

$\hat{x}$ = Bias-Corrected rainfall
x = Rainfall
F = Cumulative distribution probability function (CDF),
O = Observed,
m = Climate model,
h = Historical, and

p = Projected/future scenarios.

STEP-2: Generation of 15-min precipitation.

- Modified stochastic method (Socolofsky et al. (2010) (http://ascelibrary.org/doi/10.1061/%28ASCE%291084-0699%282001%296%3A4%28300%29), Mirhosseini et al. (2013 (http://link.springer.com/article/10.1007/s10113-012-0375-5))).

[VIDEO] https://res.cloudinary.com/amuze-interactive/image/upload/f_auto,q_auto/v1638489526/agu-fm2021/1b-73-70-31-f8-84-34-8b-0b-6a-ba-54-cc-5d-1b-97/image/gif_yb1uck.mp4

Fig 4: Stochastic generation of 15-min rainfall using cumulative distribution function (CDF).
where,
$\boldsymbol{D_t}$ = Depth of measured/hourly rainfall
a = Probability corresponding to $\boldsymbol{D_t}$
$\boldsymbol{U_i}$ = Uniformly distributed random number between 0 and a
$\boldsymbol{D_i}$ = rainfall event depth corresponding to $\boldsymbol{U_i}$

STEP-3: Rainfall Erosivity(R).

- Modified Agricultural Handbook (AH)−537 using recommendations from Agricultural Handbook−703 (https://agris.fao.org/agris-search/search.do?recordID=XF2015047686) and Mcgregor et.al (1995) (https://elibrary.asabe.org/abstract.asp?aid=27921).
  Recommendations:
  1. High-resolution precipitation (fixed-intensity)
  2. Includes all storms
  3. Energy equations of AH-537
  4. Maximum Intensity should not limited.
  5. No regression between R and rainfall.

a) Rainfall energy per unit depth:

$$e\left(\frac{MJ.mm}{ha.h}\right) = 0.119 + 0.0873 * log_{10}(I)$$

b) Storm Erosivity:

$$E_s\left(\frac{MJ.mm}{ha.h}\right) = \left[\sum_{t=1}^{p}(e.P)\right] I_{30}$$

c) Average annual erosivity:

$$R\left(\frac{MJ.mm}{ha.h.y}\right)=\frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(E_s)_k\right]$$

where,
I= rainfall intensity $\left(\frac{mm}{h}\right)$,
P=rainfall depth (*mm*),
I_{30} = maximum 30-minute rainfall intensity.
p = number of time segments in the event,
t=single time interval,
j = index of the number of years used to produce an average,
n = number of years used to obtain average R,
k = index of the number of storms in each year, and
m = number of storms in each year.

Narration:

4. RESULT AND DISCUSSIONS

1. Bias-correction:

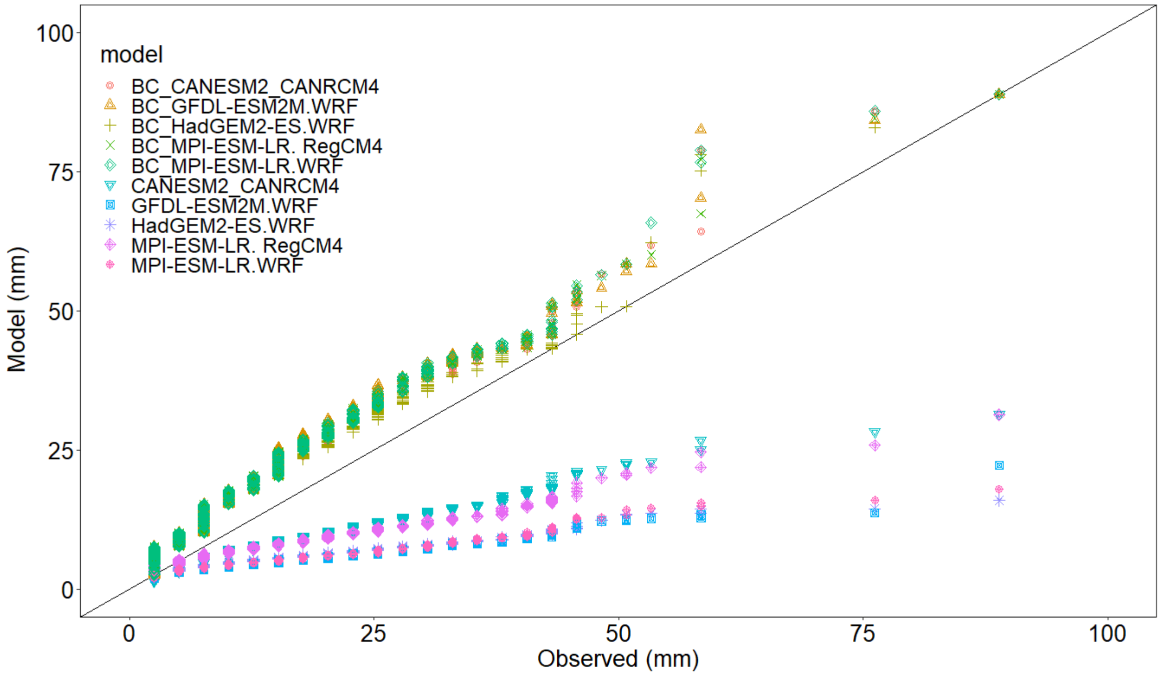


Fig 5: Quantile-quantile plot for biased-corrected and historical precipitation under different climate models (**NOTE:** BC= bias-corrected).

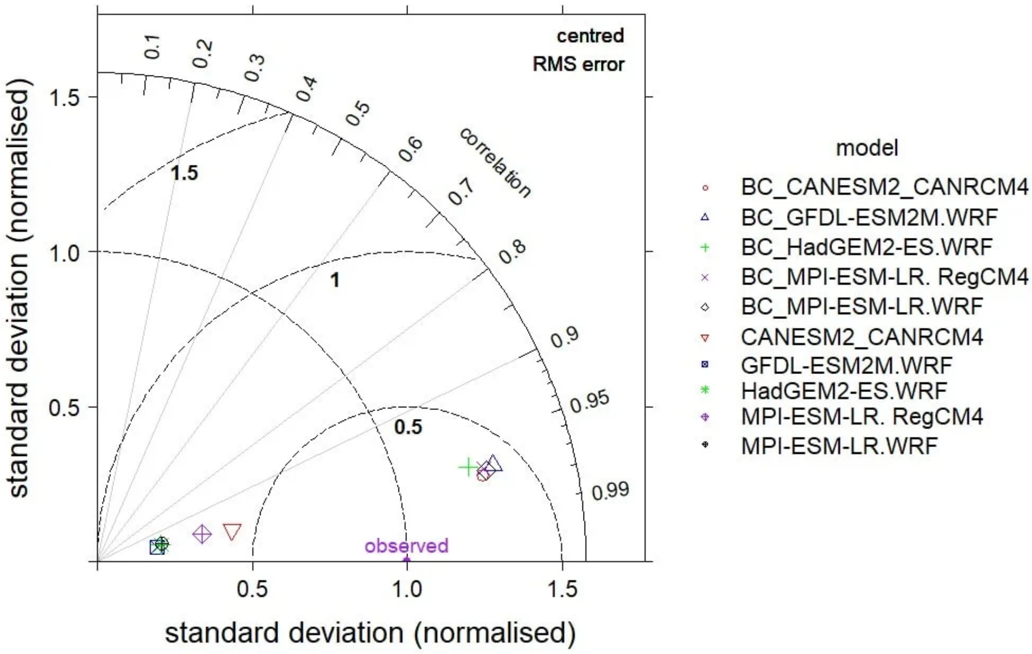


Fig 6: Taylor diagram for biased-corrected and historical hourly precipitation under different climate models.

2. Disaggregation:

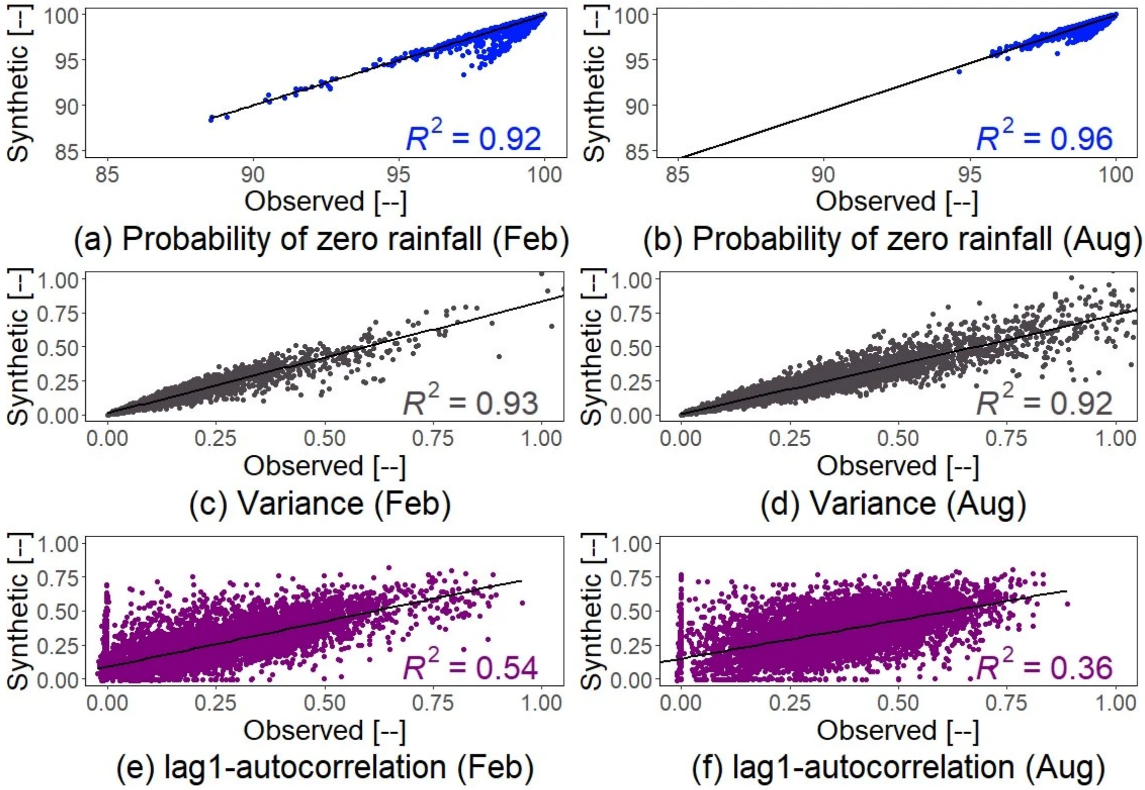


Fig 7: Statistical comparison between observed and disaggregated precipitation for winter (February) and summer (August).

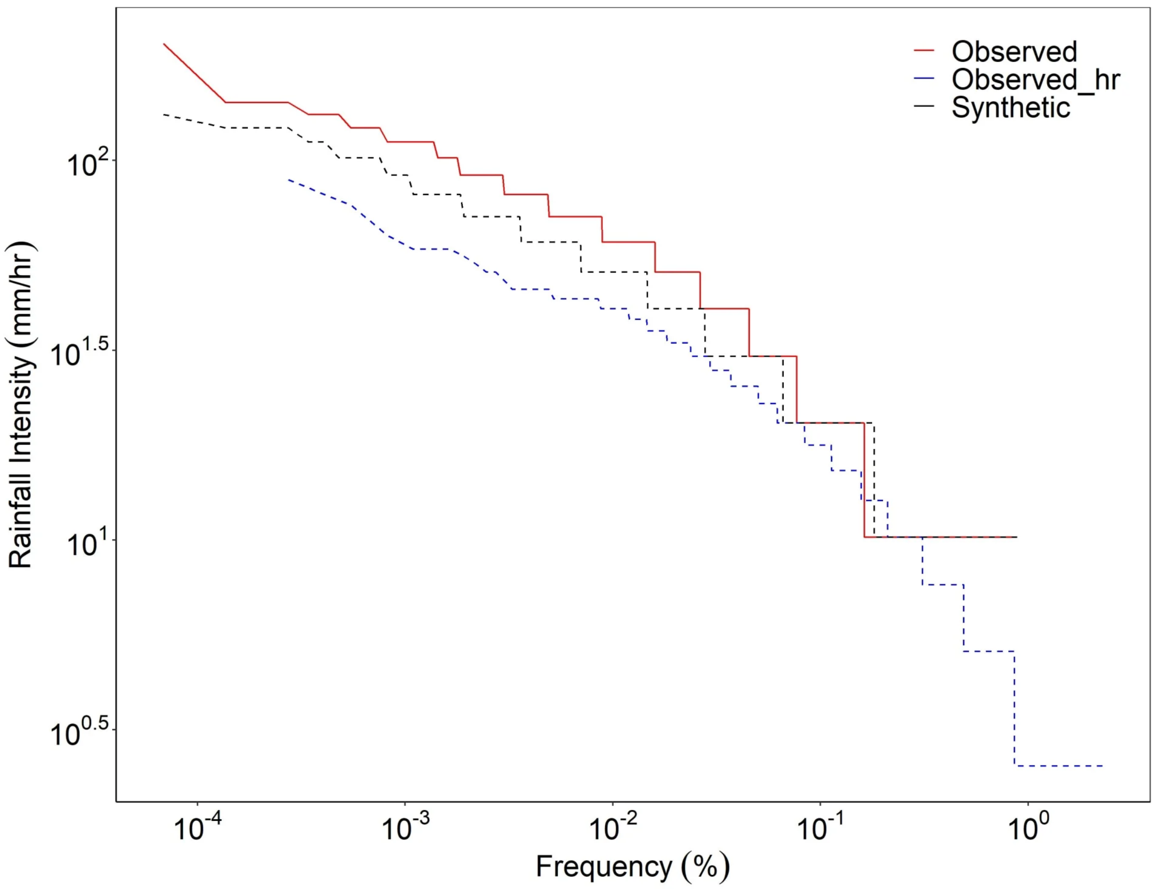


Fig 8: Comparision of precipitation intensity between observed(15-min), hourly-observed, and synthetic (15-min) precipitation.

3. Rainfall Erosivity:

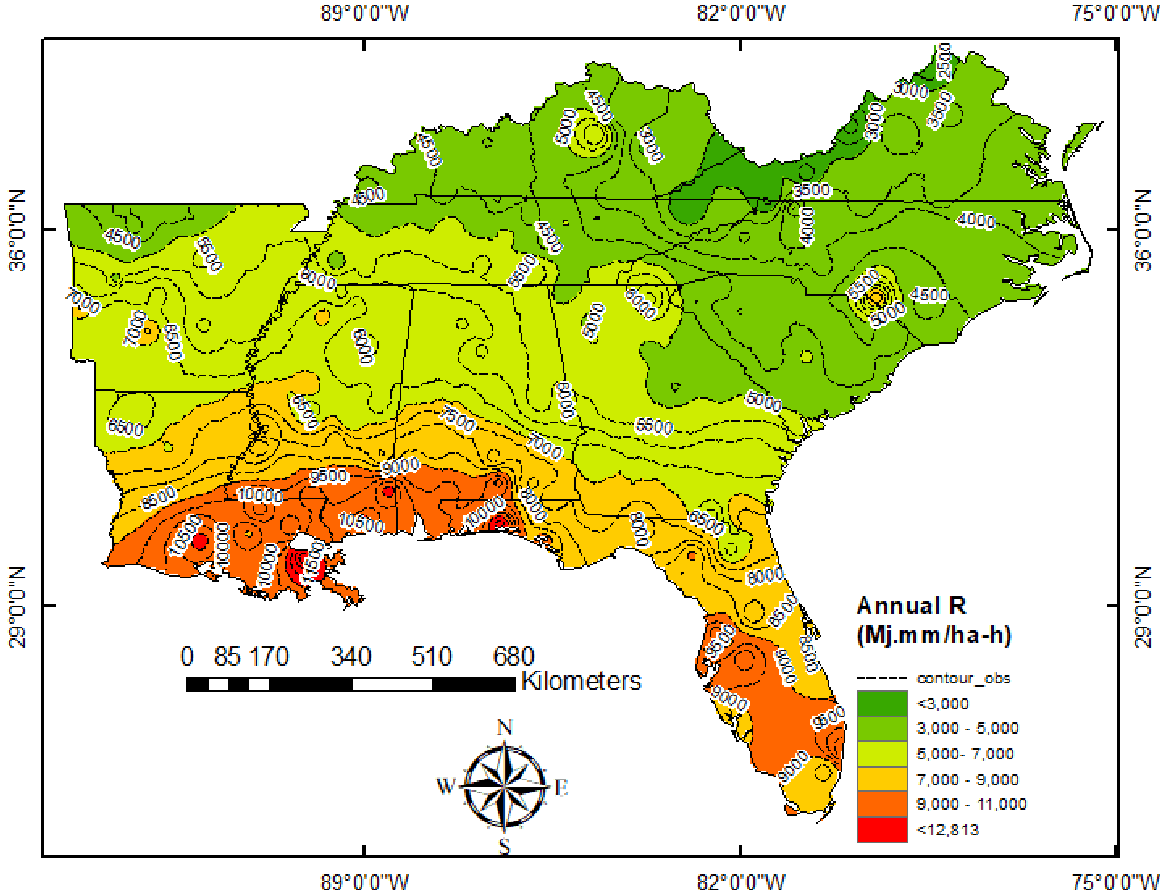


Fig 9: Observed annual rainfall erosivity (1971-2010) for Southeastern, USA.

[VIDEO] https://res.cloudinary.com/amuze-interactive/image/upload/f_auto,q_auto/v1638739142/agu-fm2021/2e-05-49-38-11-60-da-d7-90-36-24-07-0e-0f-64-9f/image/ei_argf8d.mp4

Fig 10: Projected annual average rainfall erosivity (2030-59) under different climate models.

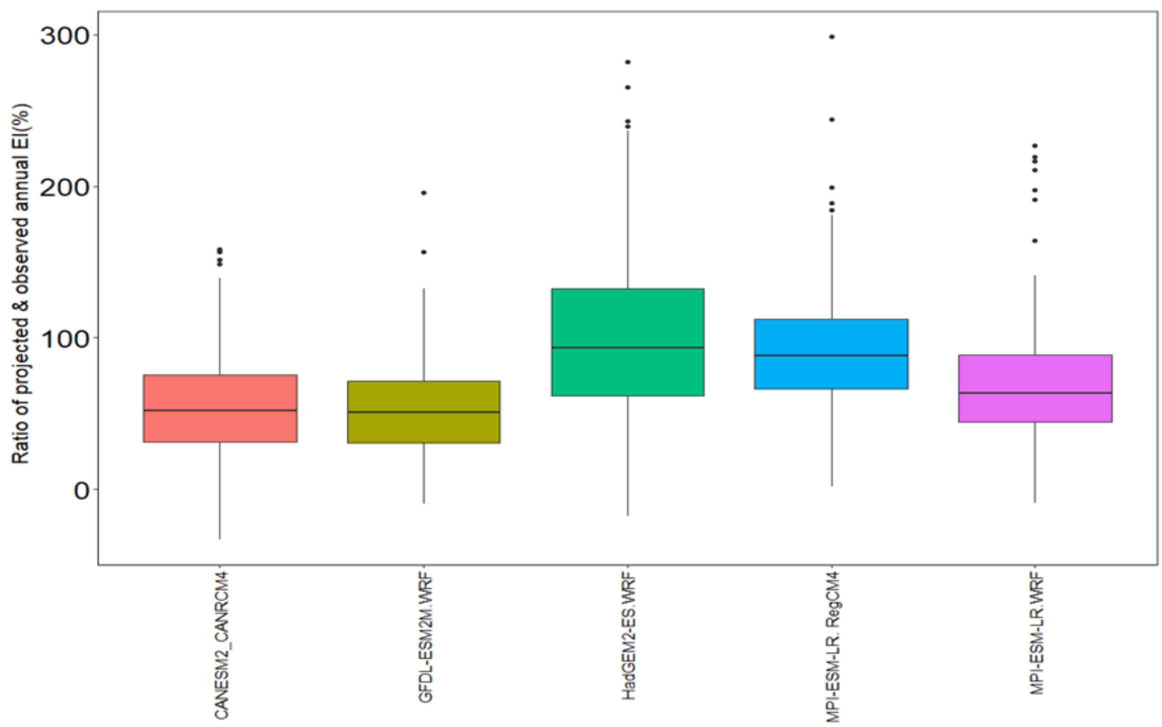


Fig 11: Boxplot for the projected relative change in annual rainfall ersovity (in %) with reference to 1970-2010 under different climate models.

Narration:

5. SUMMARY AND ACKNOWLEDGMENT

- Generated 15-min projected rainfall improved over hourly data.
- Annual rainfall erosivity is likely to increase spatial coverage.
- More reliable projected rainfall erosivity.

LIMITATIONS:

- Rainfall characteristics also might not sufficiently represent observed characteristics.
- Estimation of rainfall erosivity is applicable only for Southeastern, US.

Narration:

ACKNOWLEDGMENT:

- Auburn University Hopper Cluster for assistance with this work.
- USDA-NIFA Hatch Project (ALA014-1-19052), and Alabama Agricultural Experiment Station for the funding.

AUTHOR INFORMATION

Bijoychandra Singh Takhellambam
Graduate Research Assistant
Department of Biosystem Engineering,
Auburn University, USA.
Email:tzs0075@auburn.edu
Linkedin (http://(https://www.linkedin.com/in/takhellambam-bijoychandra-singh-3a06741b/)), Researchgate (https://www.researchgate.net/profile/Takhellambam-Bijoychandra-Singh).

ABSTRACT

Climate change will amplify erosion rates as erosive power of rainfall will likely increase due to change in rainfall characteristics (e.g., energy, intensity, duration as well as frequency). According to Intergovernmental Panel on Climate Change Fourth Assessment report (IPCC AR4), it is projected that by mid-21st Century, the rainfall across southeastern US will both increase and decrease in intensity, which will substantially affect rainfall erosivity. Few studies have estimated the impact of climate change (e.g., rainfall intensity) on rainfall erosivity across US and around the world. However, previously published erosion indices have discrepancies due to differences in methodologies (e.g., primarily omission of small and low rainfall intensity) adopted in those studies. Therefore, the objective of this study was to estimate change in erosion indices for the period 2030-2059 using the benchmark rainfall indices established for southeastern region of US. Hourly precipitation data were retrieved from NA-CORDEX under Representative concentration pathways (RCP) 8.5. Results on change in erosion indices as a result of climate change will be presented.

REFERENCES

Choi, J., Socolofsky, S. A. & Olivera, F. Hourly disaggregation of daily rainfall in Texas using measured hourly precipitation at other locations. Journal of Hydrologic 575 Engineering 13, 476–487 (2008).

McGehee, R. & Srivastava, P. Benchmarking reliable erosion indices from quarter-hour station data for climate studies in the southeastern United States. Journal of Soil and 560 Water Conservation 73, 363–376 (2018).

McGregor, K. C., Bingner, R. L., Bowie, A. J. & Foster, G. R. Erosivity index values for Northern Mississippi. Transactions of the ASAE 38, 1039–1047 (1995).

Mirhosseini, G., Srivastava, P. & Stefanova, L. The impact of climate change on rainfall Intensity–Duration–Frequency (IDF) curves in Alabama. Reg Environ Change 13, 25–33 519 (2013).

Socolofsky, S., Adams, E. E. & Entekhabi, D. Disaggregation of daily rainfall for continuous watershed modeling. Journal of Hydrologic Engineering 6, 300–309 (2001).

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Avery, M. Tignor, and H.L. Miller (eds.). (2007): Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA.

Takhellambam, B. S. Temporal disaggregation of hourly projected precipitation over the Southeast United States. figshare https://figshare.com/s/d6b129110dc47fa2671d 657 (2021).