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A Space-Time Modeling Framework for Streamflow Extremes

Alvaro Ossandon[1,2], Balaji Rajagopalan[1,3], William Kleiber[4]
alvaro.ossandon@colorado.edu

1. CEAE, University of Colorado, Boulder CO,
2. Department of Civil Engineering, Santa Maria University, Valparaiso, Chile,
3. CIRES, University of Colorado, Boulder CO,
4. Department of Applied Mathematics, University of Colorado, Boulder CO.

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University of Colorado Boulder

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Overview

- Motivation
- Model structure
- Study area and data
- Covariates
- Adequacy of the models
- Results
- Summary

Motivation

- Summer seasonal streamflow in monsoon climate makes a significant contribution to the reliability of water resources and the health of ecology
- The summer extreme precipitation and streamflow also cause severe floods resulting in loss of life and property
- Large scale climate drivers impart strong spatial and temporal variability in the flow extremes

need to be modeled for use in efficient management of resources

Chennai Floods of 2015

Arizona, July 2018

Model Structure

- At each site, 3-day maximum summer streamflow is modeled as a GEV with time varying parameters

$$Q_i(t) \sim GEV\big(\mu_i(t), \sigma_i(t), \xi_i(t)\big), \qquad i = 1, \dots, m$$

where

$$\mu_i(t) = \alpha_{\mu 0_i} + \sum_{j=1}^{3} \alpha_{\mu j_i} z_j(t), \qquad i = 1, \dots, m$$

$$\log(\sigma_i(t)) = \alpha_{\sigma 0_i} + \sum_{j=1}^{3} \alpha_{\sigma j_i} z_j(t) \qquad i = 1, \dots, m$$

$$\xi_i(t) = \alpha_{\xi 0_i}, \qquad i = 1, \dots, m$$

Model Structure

- To capture the spatial and temporal dependence a Gaussian copula was fitted

$$\boxed{\big(Q_1(t), \dots, Q_m(t)\big) \sim C_g(\boldsymbol{\Sigma}; \{\boldsymbol{\mu}(t), \boldsymbol{\sigma}(t), \boldsymbol{\xi}(t)\})}$$

where

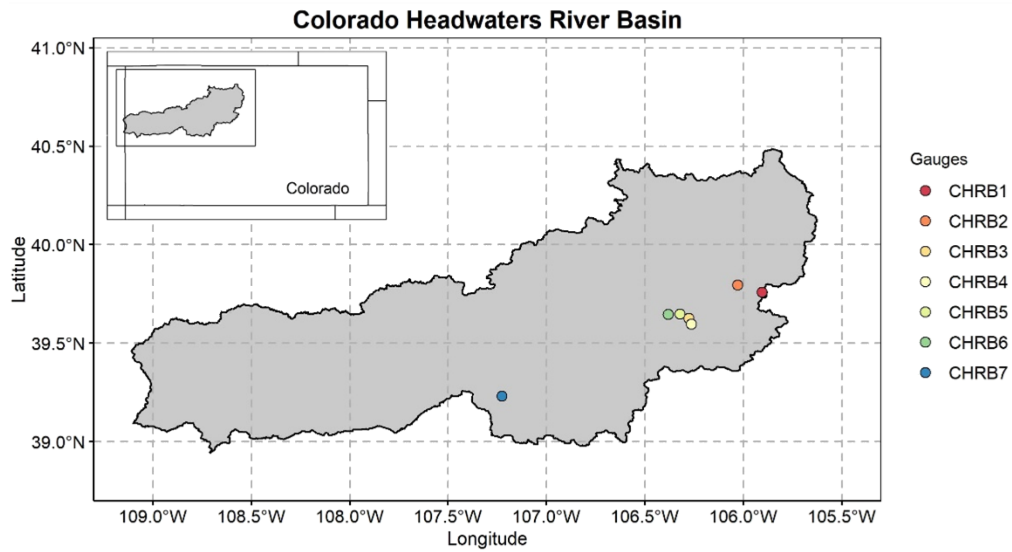
$$\boldsymbol{\Sigma} = \begin{bmatrix} 1 & c_{12} & \cdots & c_{1(m-1)} & c_{1m} \\ c_{12} & 1 & \ddots & \vdots & c_{2m} \\ c_{13} & c_{23} & \ddots & \vdots & \vdots \\ \vdots & \vdots & \ddots & 1 & c_{(m-1)1} \\ c_{1m} & c_{2m} & \cdots & c_{(m-1)1} & 1 \end{bmatrix}$$

Since $\boldsymbol{\Sigma}$ is symmetric, only $m(m-1)/2$ need to be fitted

Study area and data: Southwest U.S.

Streamflow

- Daily observed streamflow – U.S. Geological Survey (USGS)
- Years: 1964-2018, no. of sites 7
- 3-day maximum summer streamflow was computed from daily streamflow



Covariates

- ENSO and PDO climate indices (https://www.esrl.noaa.gov/psd/data/climateindices/list/)
- Daily observed precipitation – Global Historical Climatology Network (GHCN) dataset (https://www1.ncdc.noaa.gov/pub/data/ghcn/daily/)
- No. of stations 5 (Colorado Headwaters River Basin)
- Regional mean precipitation (SASTP) was computed from daily precipitation

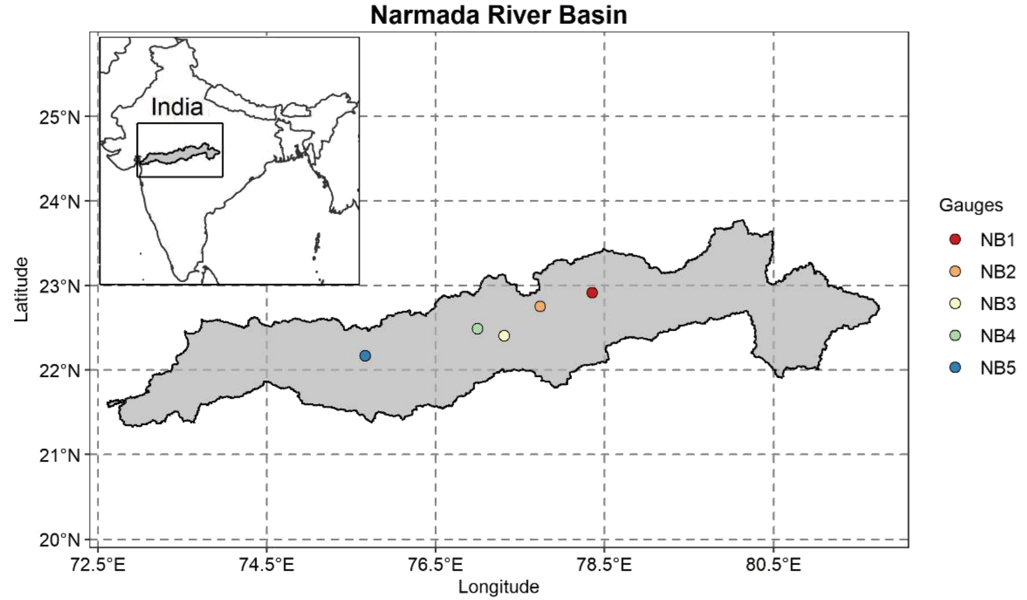
Code	Name
CHRB1	Bobtail creek near jones pass
CHRB2	South fork of Williams fork near leal
CHRB3	Gore creek at upper station, near minturn
CHRB4	Black gore creek near minturn
CHRB5	Booth creek near minturn
CHRB6	Middle creek near minturn
CHRB7	Crystal river above avalanche creek, near redstone

Study area and data: India

Streamflow

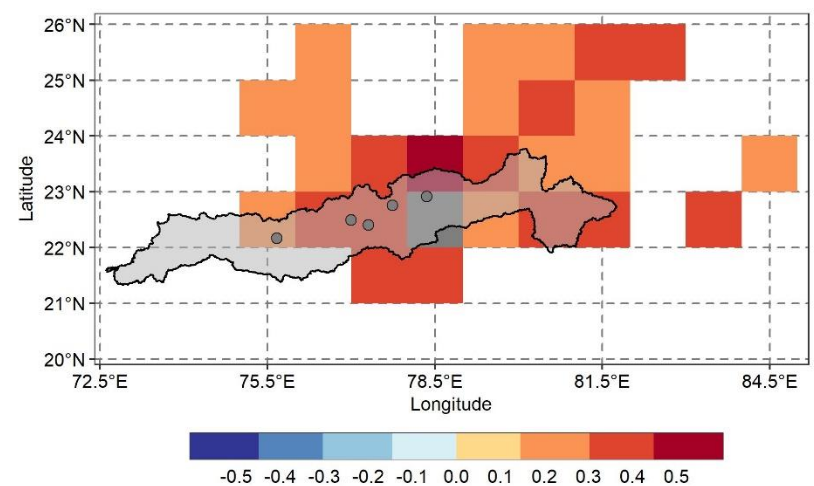
- Daily observed streamflow – India Water Resource Information System (IWRIS)
- Years: 1979-2013, no. of sites 5
- 3-day maximum summer streamflow was computed from daily streamflow

Code	Name
NB1	Sandia
NB2	Hoshangabad
NB3	Chhidgaon
NB4	Handia
NB5	Mandleshwar



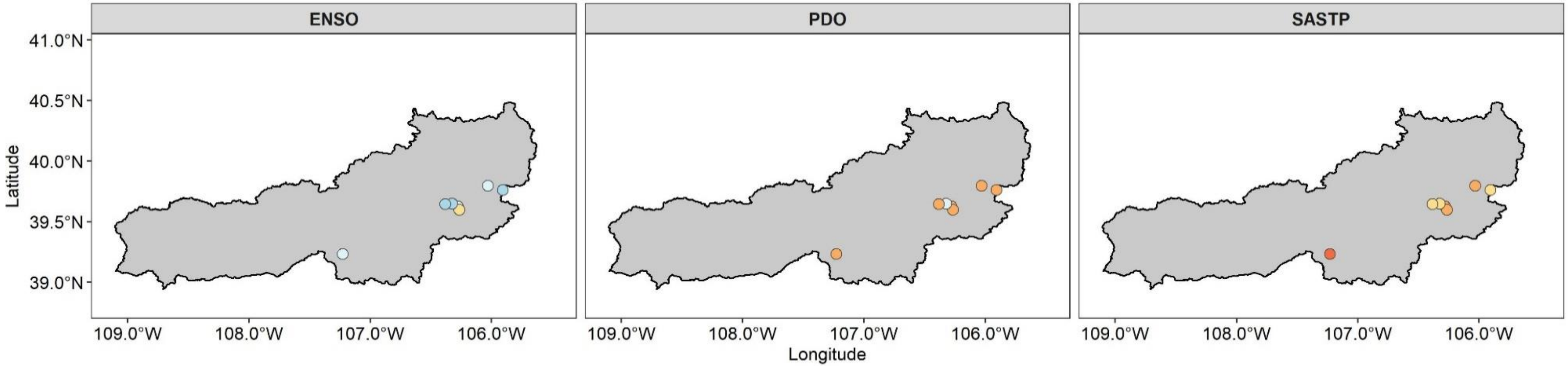
Covariates

- ENSO and IOD climate indices (https://psl.noaa.gov/gcos_wgsp/Timeseries/DMI/)
- Daily observed grid precipitation – India Meteorology Department (IMD)
- Regional mean precipitation (SASTP) was computed from daily precipitation. Only grids with high correlation were considered

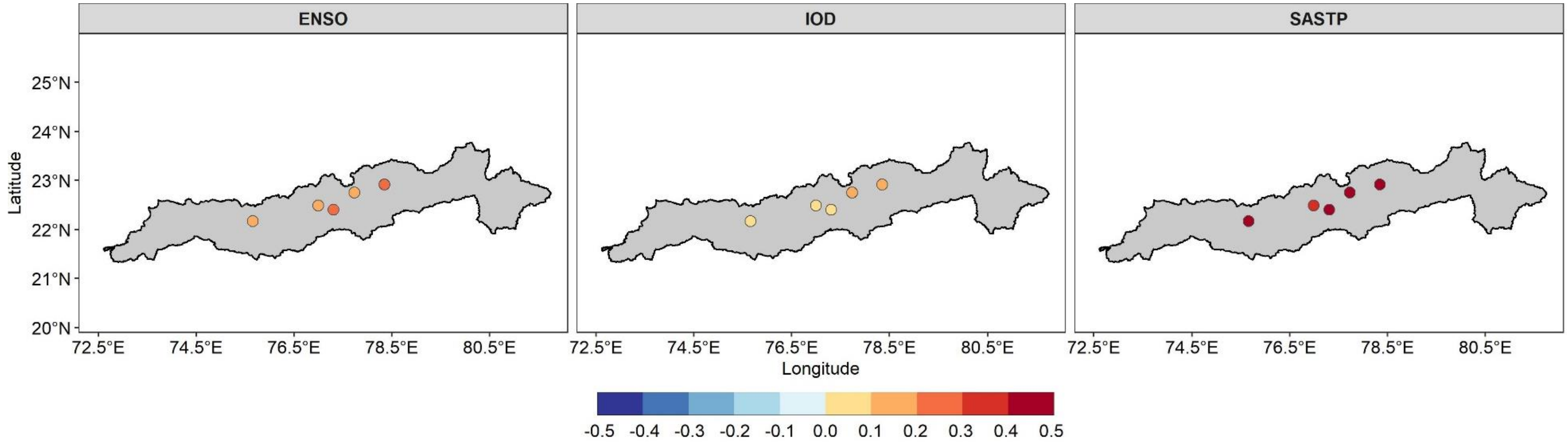


Covariates

Colorado Headwaters River Basin, Southwest U.S.



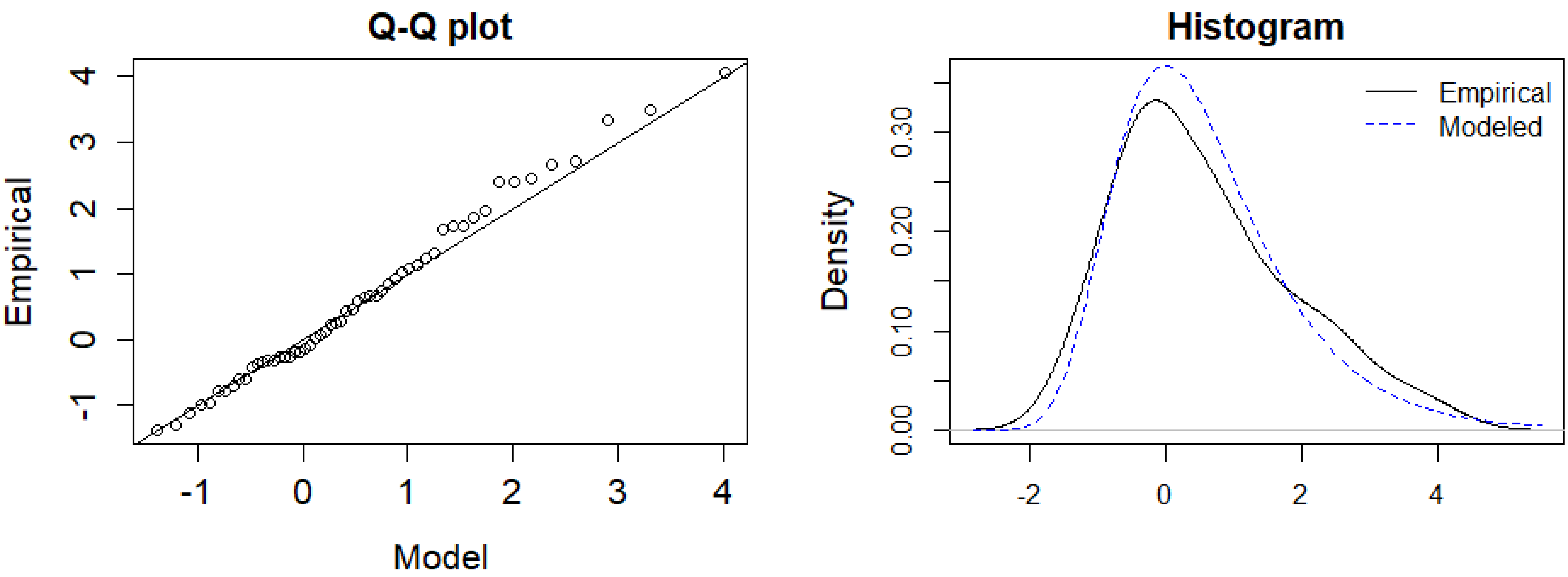
Narmada River Basin, India



Adequacy of GEV distribution

- Good GEV fitting for all the sites

Crystal river above avalanche creek, near redstone, CO (CHRB7)



Adequacy of Gaussian Copula

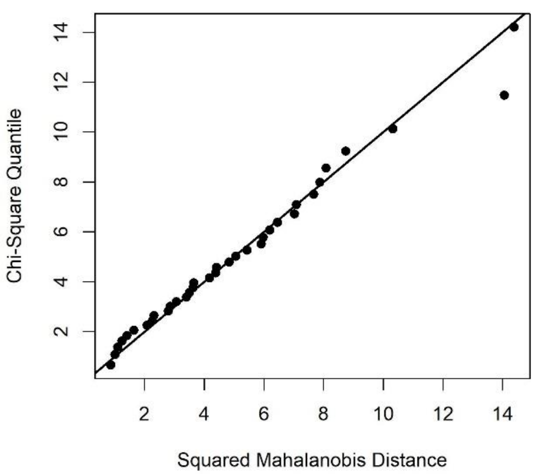
We ran three multivariate normality tests using marginal transformations based on the MLE GEV fits:

- Mardia's (Mardia, 1970)
- Royston's (Royston, 1982)
- Doornik-Hansen's (Doornik & Hansen, 2008)

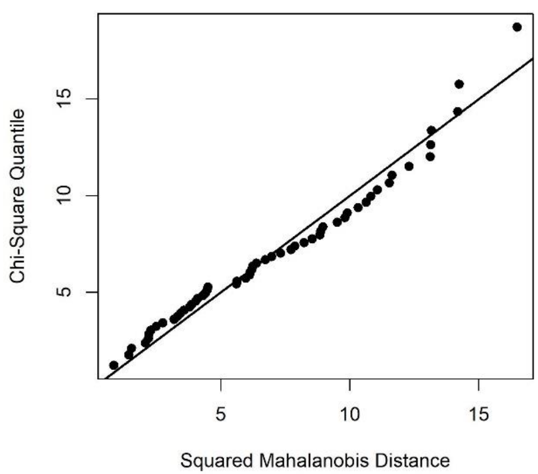
The p-values for the three tests indicated the transformed data follow a multivariate normal distribution

Chi-Square Q-Q plots from Royston's test

Narmada River Basin

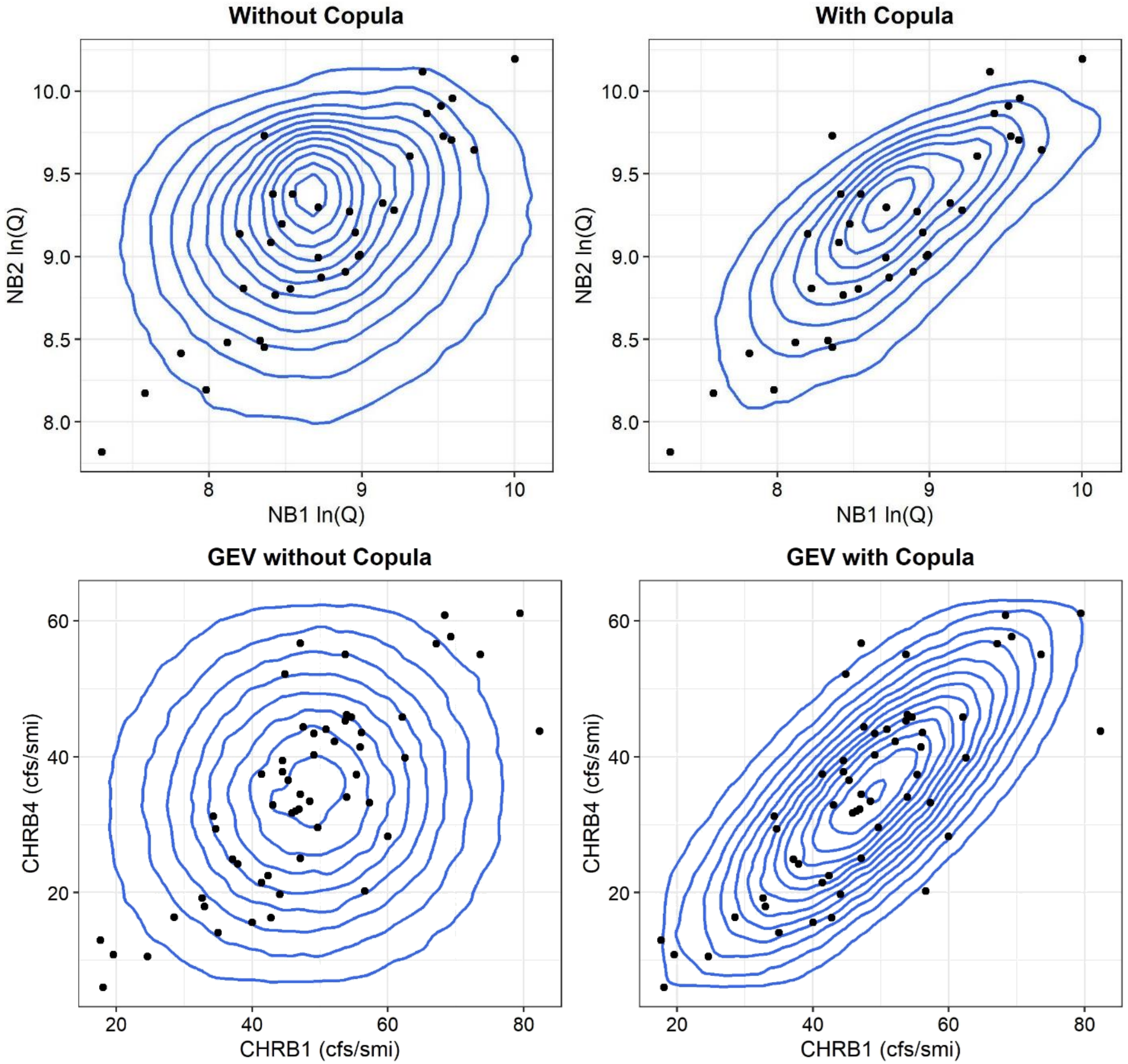


Colorado Headwaters RB



Results: Pairwise dependence structure simulated

Gaussian copula can capture the structure of the pairwise dependence for both study cases

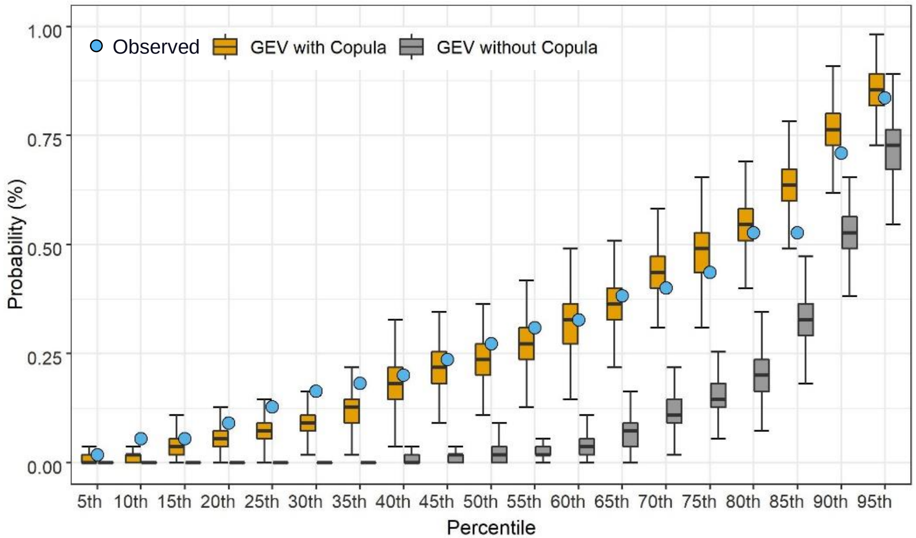


Results: Temporal dependence

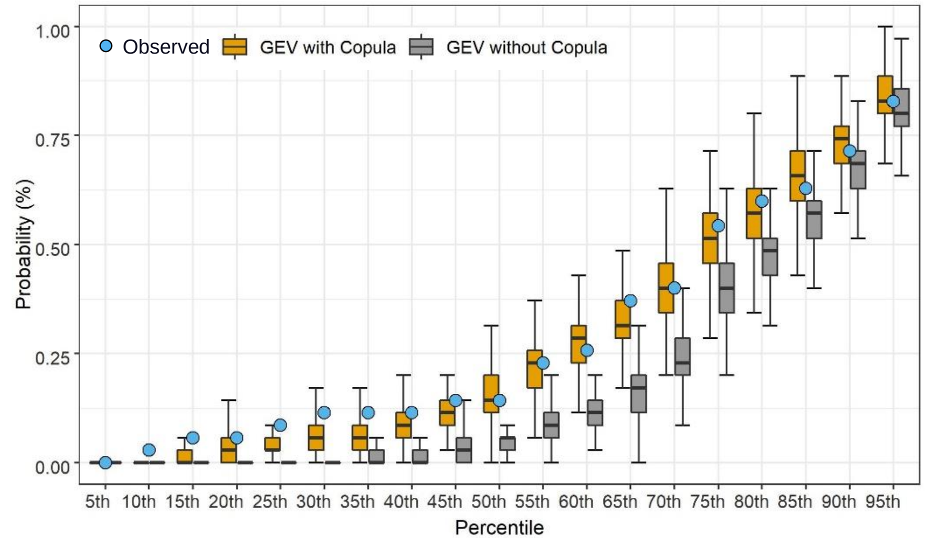
We computed the probability that all gauges do not exceed their kth percentile

- For each year we defined if all the gauges do not exceed their kth percentile
- The probability corresponds to the number of year in which all gauges do not exceed their kth percentile over the number of years.

Colorado Headwaters River Basin



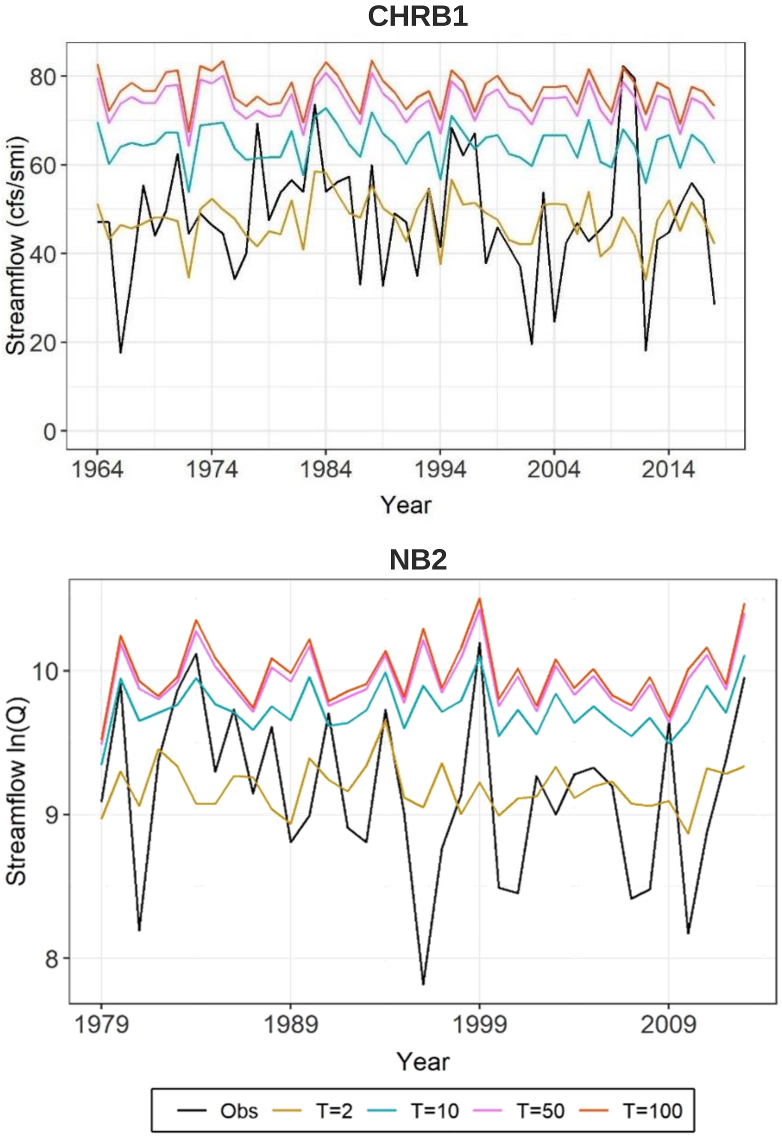
Narmada River Basin



Gaussian copula can capture the temporal dependence of the gauges

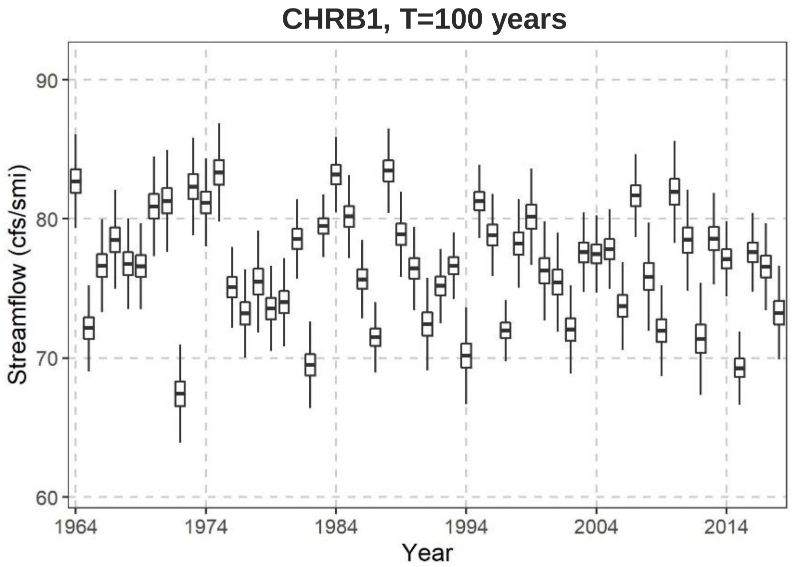
Results: Temporal variability of return levels

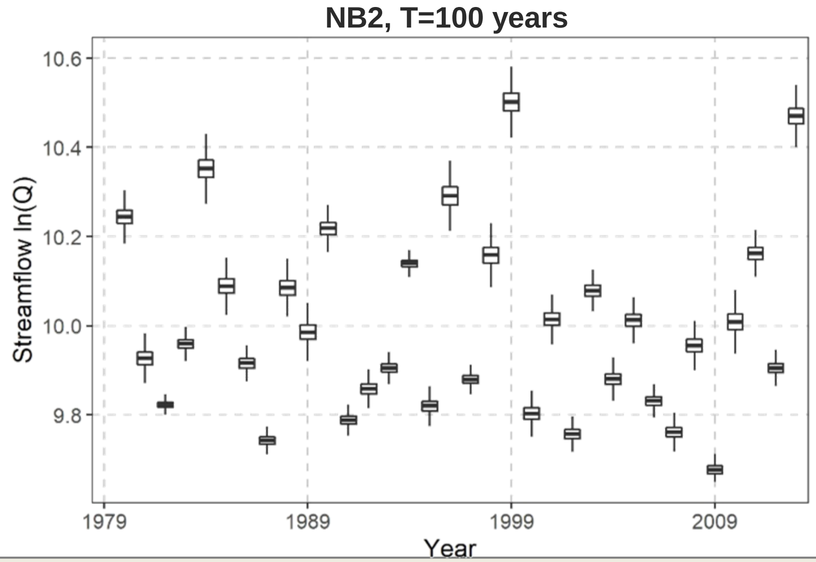
nonstationary return levels capture the inter-annual variability of the observed streamflow extremes very well



Results: Temporal variability of return levels

The uncertainty is not high for both cases





Summary

- Developed a space-time model to capture the variability of summer season 3-day maximum streamflow
- The parameters of the GEV distribution vary with time/covariates
- Gaussian copula can capture the structure of the pairwise dependence
- Gaussian copula can capture the temporal dependence of the gauges
- Nonstationary return levels capture the inter-annual variability of the observed streamflow extremes very well with a reduced uncertainty
- Provide non-stationary estimates of risk of various thresholds

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