Modeling fish species diversity in river networks

Richa Tripathi[1*], Adam Mertel[1], Guohuan Su[1], Jeffrey Kelling[2,3], Justin M. Calabrese[1,4,5]

[1]Center for Advanced Systems Understanding (CASUS), Helmholtz-Zentrum Dresden - Rossendorf, 02826 Görlitz, Germany

[2]Helmholtz-Zentrum Dresden - Rossendorf, 01314 Dresden, Germany

[3]Chemnitz University of Technology, 09111 Chemnitz, Germany

[4]Department of Biology, University of Maryland, College Park, USA

[5]Department of Ecological Modelling, Helmholtz Centre for Environmental Research-UFZ, 04318 Leipzig, Germany

Introduction

- River basins across the world are shaped by local land topography and generally have a dendritic structure formed by convergence of river streams originating in a watershed until they end up in the main river.

- They are home to a plethora of aquatic lifeforms. Movement patterns of riverine biodiversity, especially fishes, are shaped by dendritic structure of river networks (see Figure) and habitat capacity of river basins [1].

- Neutral biodiversity models [2] have been able to successfully explain a suite of biodiversity indices of plant and animal species across various ecological systems, but have been poorly studies for systems characterized by dendritic geormetry [1].

- The river networks project at CASUS is aimed at developing models to study the effects of dendritic network topology on fish biodiversity.

Mississippi-Missouri River System (MMRS)

River Network
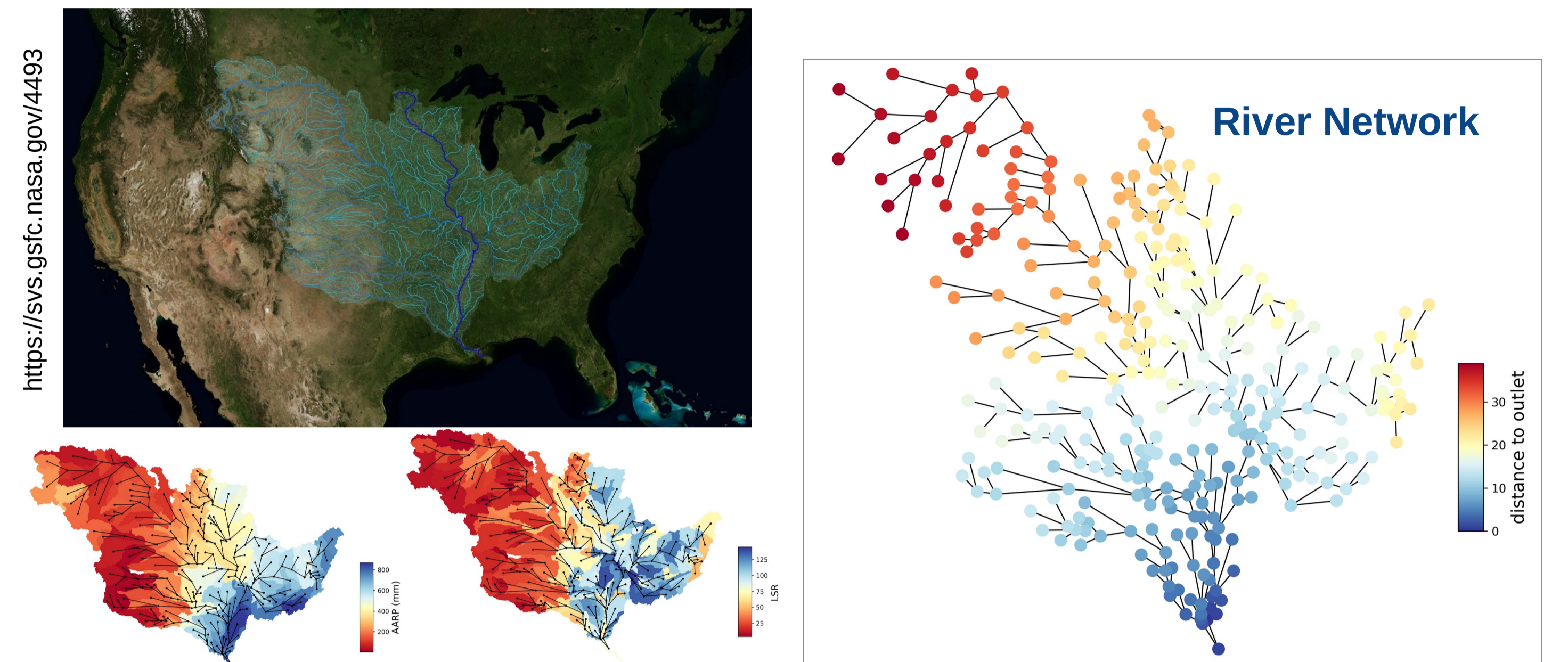
Neutral Model of Biodiversity

Under `neutral' assumption, species are assumed to be equivalent on a *per capita* basis [2]. Species abundances are evolved via Markovian process until the system reaches a steady state.


Habitat capacity:

$$HC_i = C_H * N * \frac{AARP_i * WA_i}{\sum_{i=1}^{N}(AARP_i * WA_i)}$$

Dispersal Kernel:

$$K_{ij} = C\left[a^{L_{ij}} + \frac{b^2}{L_{ij}^2 + b^2}\right]$$

Dispersal probability:

$$P_{ij} = (1-v)\frac{K_{ij}H_j}{\sum_{k=1}^{N} K_{ik}H_k}$$

v is diversification probability
L_{ij} is the topological distance between nodes i & j
WA is the watershed area, AARP is average annual runoff production
N is the number of sites in the system
a, b set local and global dispersal over the network
C_H sets habitat capacity of the system
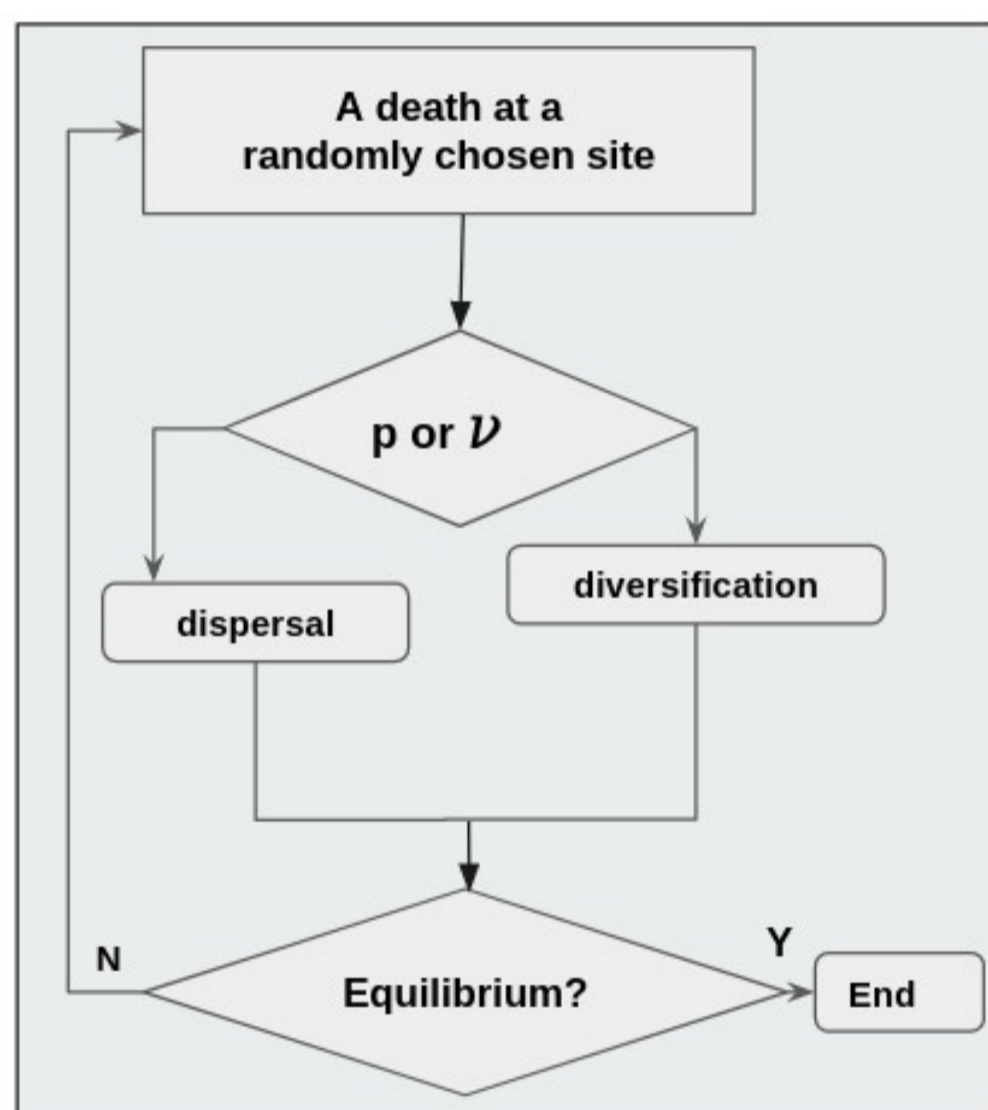
Impact of dendritic geoemtry: Square Lattice vs. Optimal Channel Network (OCN)

Square Lattice — ---- mean = 51.82

OCN — ---- mean = 70.84
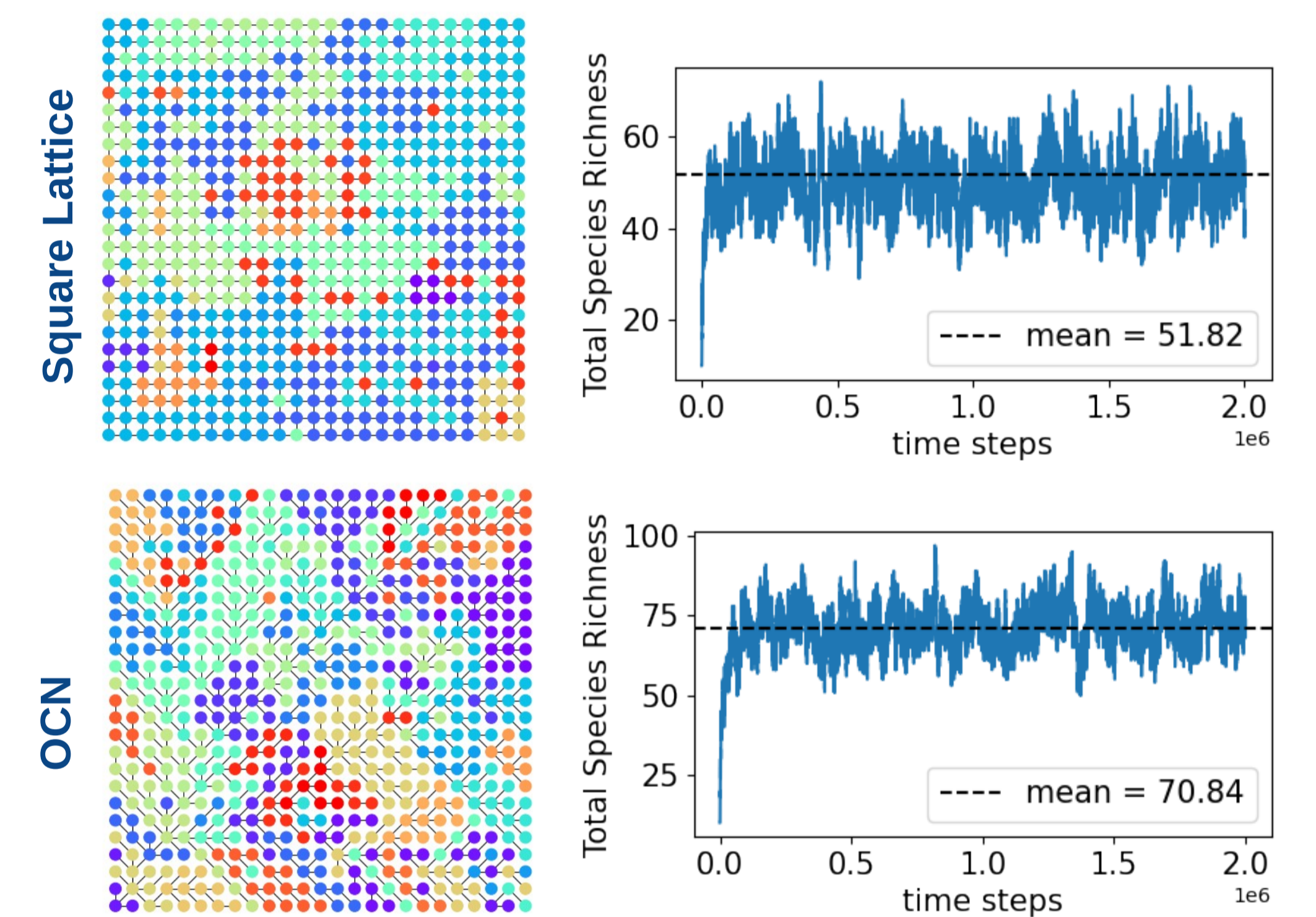
Steps:

- Obtain a river network, watershed area, runoff from hydrological data.
- Obtain local species richness (LSR), species occurrences for finding empirical biodiversity patterns.
- Set neutral model parameters, and probabilities of dispersion.
- Run the neutral model, until the steady-state is reached. Obtain the model biodiversity patterns.
- Re-calibrate the model by optimizing the parameters.

**a** = 0.7, **b** = 0.01, **C_H** = 400, **v** = 0.0001, **updates** = 8×10^7
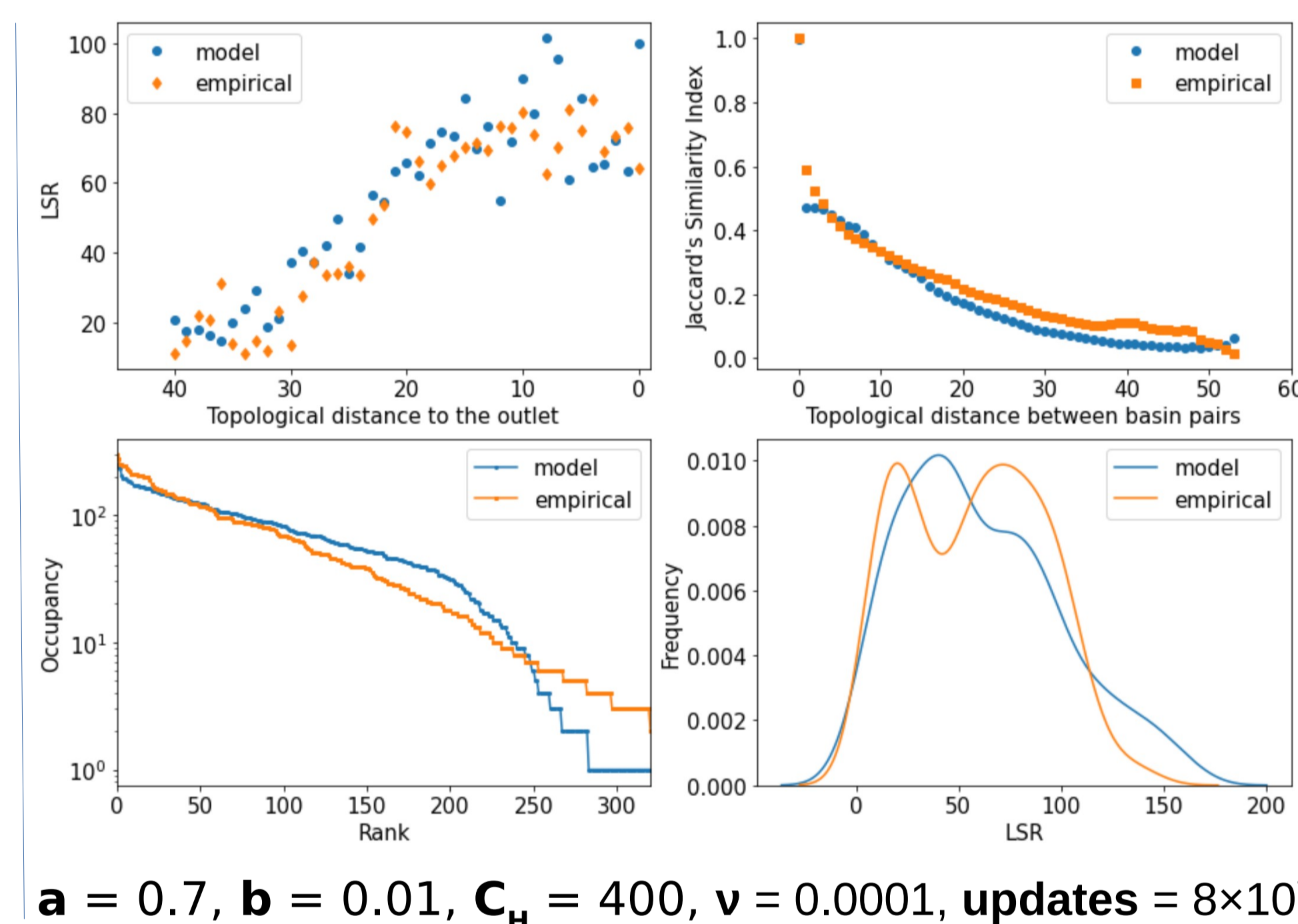
Results (on MMRS network)

Model LSR (alpha diversity) and Jaccard Similarity Index (for beta diversity) trend matched with that of empirical. Model results do not perfectly reproduce the empirical bi-modal distribution of LSR and straight line nature of the rank-occupancy curve.

Sequential versus Parallel implementation (on Tesla V100-SXM2):
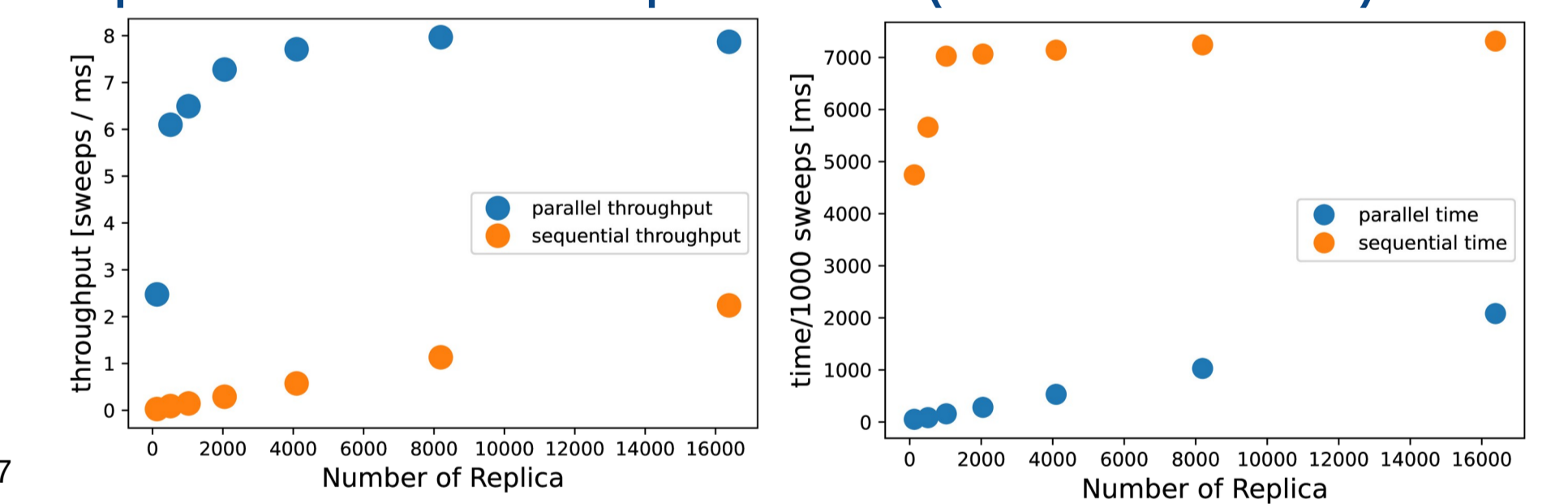
Network versions for the MMRS:

Binary Tree

Non-binary Tree
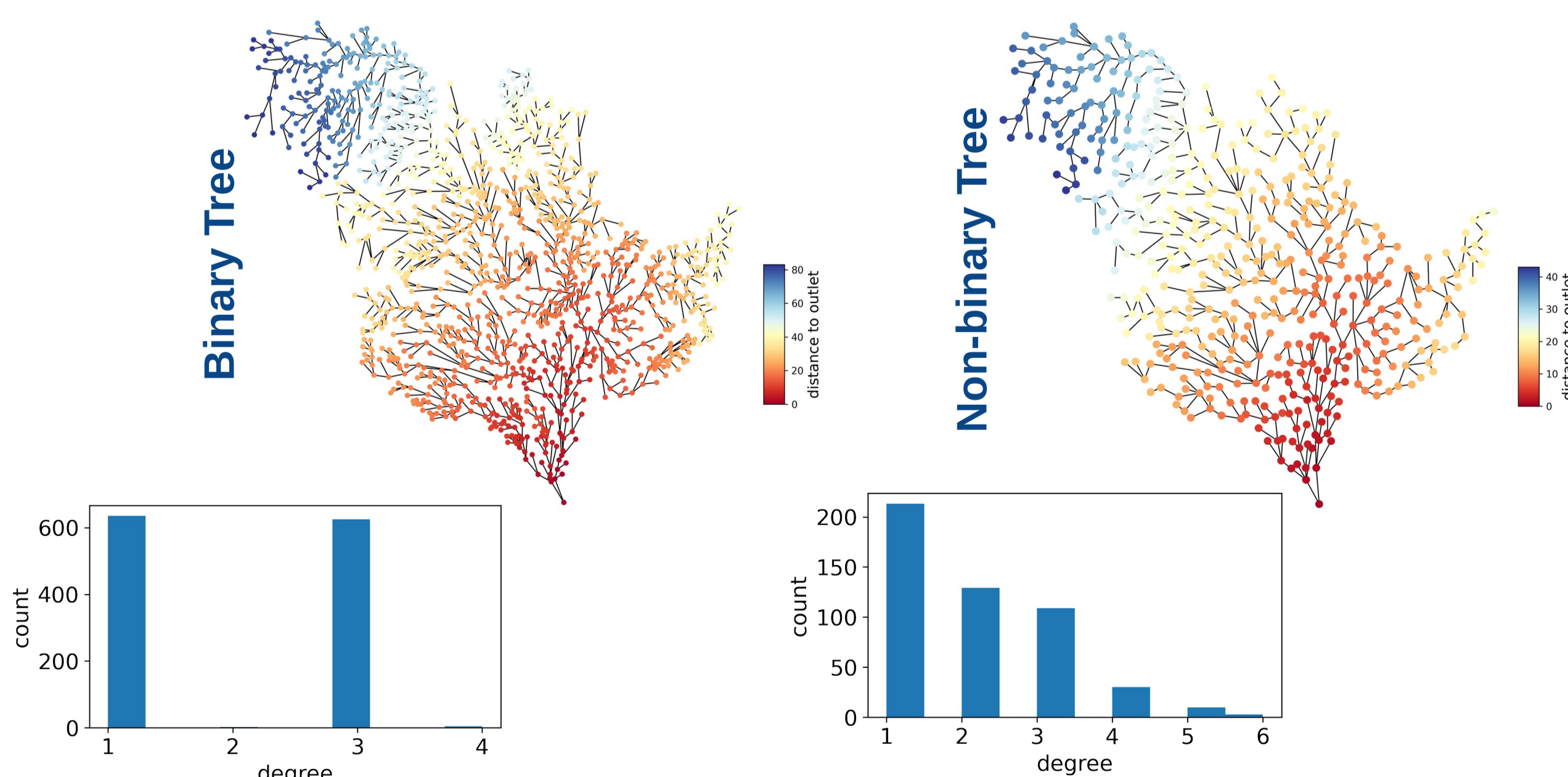
Challenges and Outlook

There are different possible network representations of the same river system. Our goal is to reproduce the empirical patterns for all geometries and compare them. The sequential implementation of the model is a computationally heavy task. We are exploring parallel implemetation on GPU. Our initial results are promising.

Biodiversity modeling enables understanding the factors shaping present biodiversity and allows us to simulate how climate change might affect future riverine biodiversity.

References:

[1] Hubbell, S. P. (2011). The unified neutral theory of biodiversity and biogeography(MPB-32). In The Unified Neutral Theory of Biodiversity and Biogeography(MPB-32). Princeton University Press.

[2] Muneepeerakul, R., Bertuzzo, E., Lynch, H. J., Fagan, W. F., Rinaldo, A., & Rodriguez-Iturbe, I. (2008). Neutral metacommunity models predict fish diversity patterns in Mississippi–Missouri basin. Nature, 453(7192), 220-222.

*r.tripathi@hzdr.de