Technische Universität München

ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

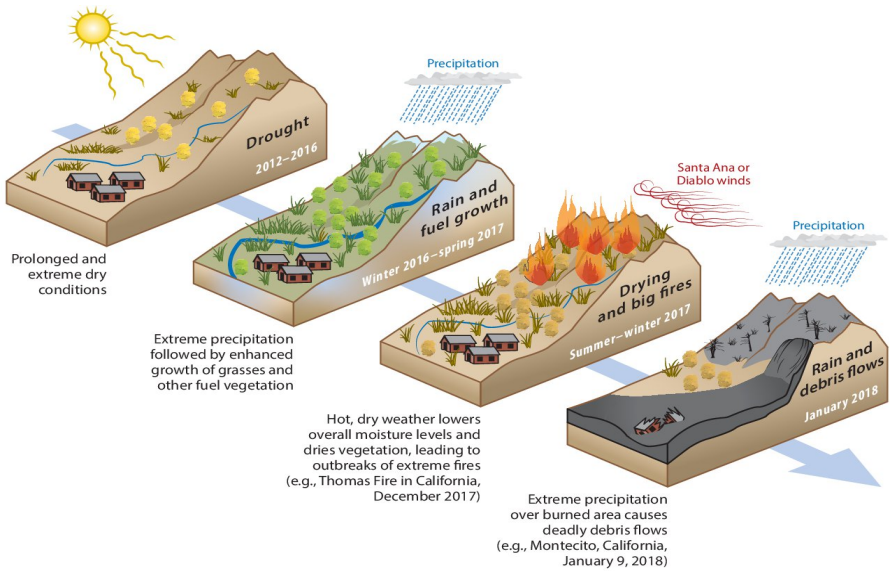
Impacts of Climate Change on Drought Cascades in Central Asia Using A Novel Self-Evolutionary Complex Network Approach

Lu Tian[1], Joshua Holzer[1], Milun Chen[1], Qing Lin[2], Markus Disse[1], Jingshui Huang[1]

[1]Chair of Hydrology and River Basin Management, Technical University of Munich

[2] Center for International Development and Environmental Research, Justus Liebig University Giessen

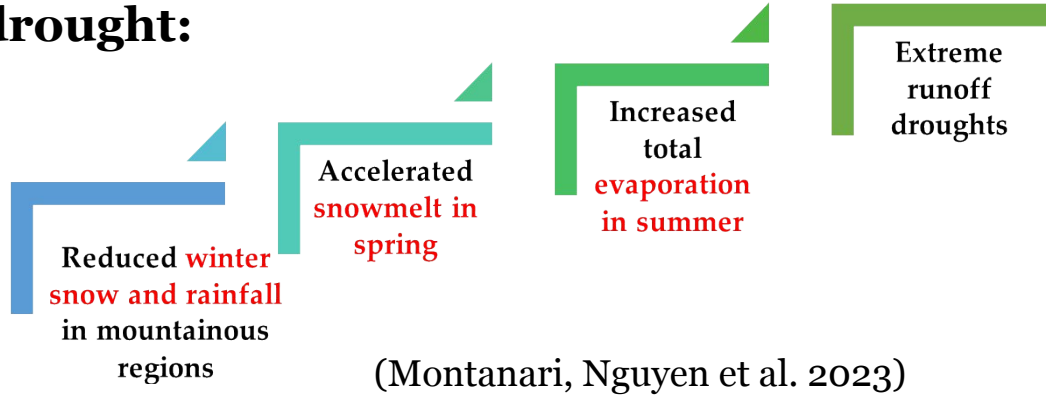
Motivation



AghaKouchak, A., Chiang, F., Huning, L.S., Love, C.A., Mallakpour, I., Mazdiyasni, O., Moftakhari, H., Papalexiou, S.M., Ragno, E. and Sadegh, M., 2020. Climate extremes and compound hazards in a warming world. Annual Review of Earth and Planetary Sciences, 48: 519-548.

- More frequent cross-system contiguous drought episodes
- Extreme droughts occurred in 2018 and 2022.

Cascading drought episode behind the 2022 Po River drought:



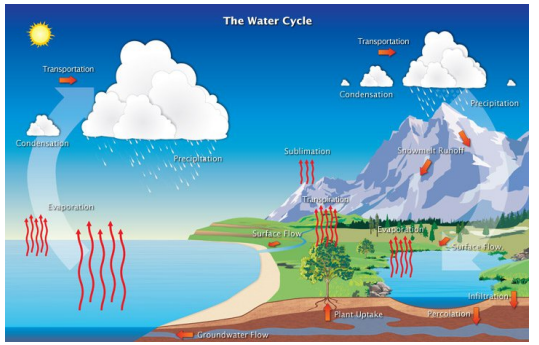
(Montanari, Nguyen et al. 2023)

ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

Motivation

Challenge

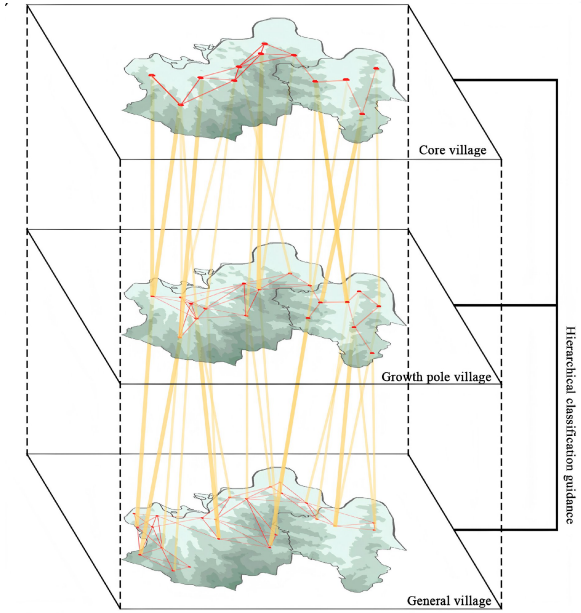
- Long-ranged cross-spatiotemporal scales interaction
- Nonlinear interactions
- Feedback loops

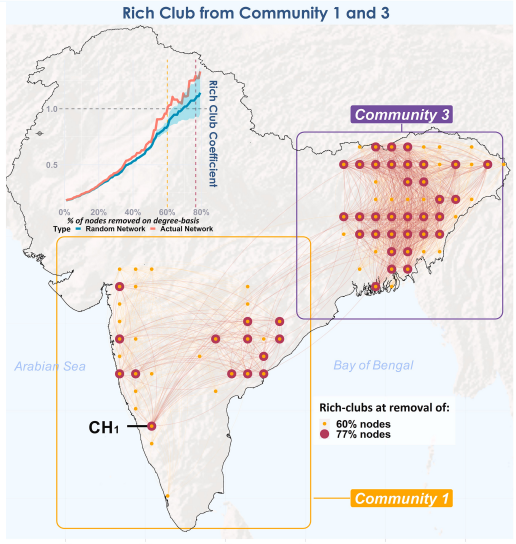


Methodology- Hierarchical complex network

- Drought pixel-based interaction
- Holistic emergent pattern: spatial connectivity

  (e.g., drought hub)





(Muthuvel, Dineshkumar, 2024)

Limitations

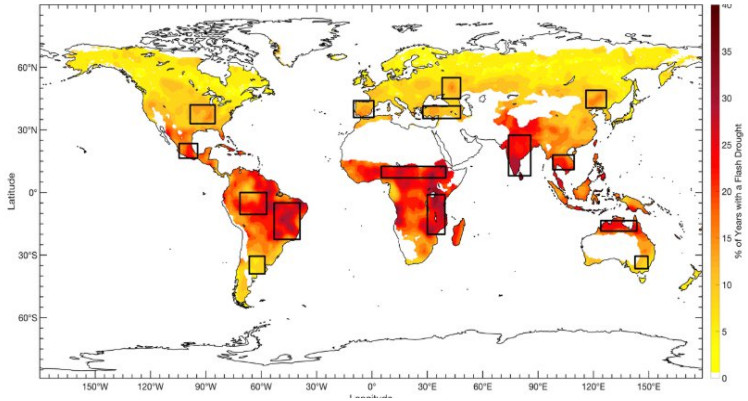
- High dimensionality causes the difficulty in detecting long-term interaction.
- Cross-temporal interaction
- Detection the extreme events

ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

Motivation & Objective

The impact climate change on droughts

- **Droughts features**
- **Drought type:** Flash droughts / Megadroughts
- **Drought evolution regimes:** e.g., Shift in water-limited or energy-limited regimes



Yuan, X., Wang, Y., Ji, P., Wu, P., Sheffield, J., and Otkin, J. A.: global transition to flash droughts under climate change, ***Science****, 380, 187–191, https://doi.org/10.1126/science.abn6301, 2023.*

Can global warming accelerate the cascading interaction in cross-system drought evolution? (between precipitation and runoff drought events)

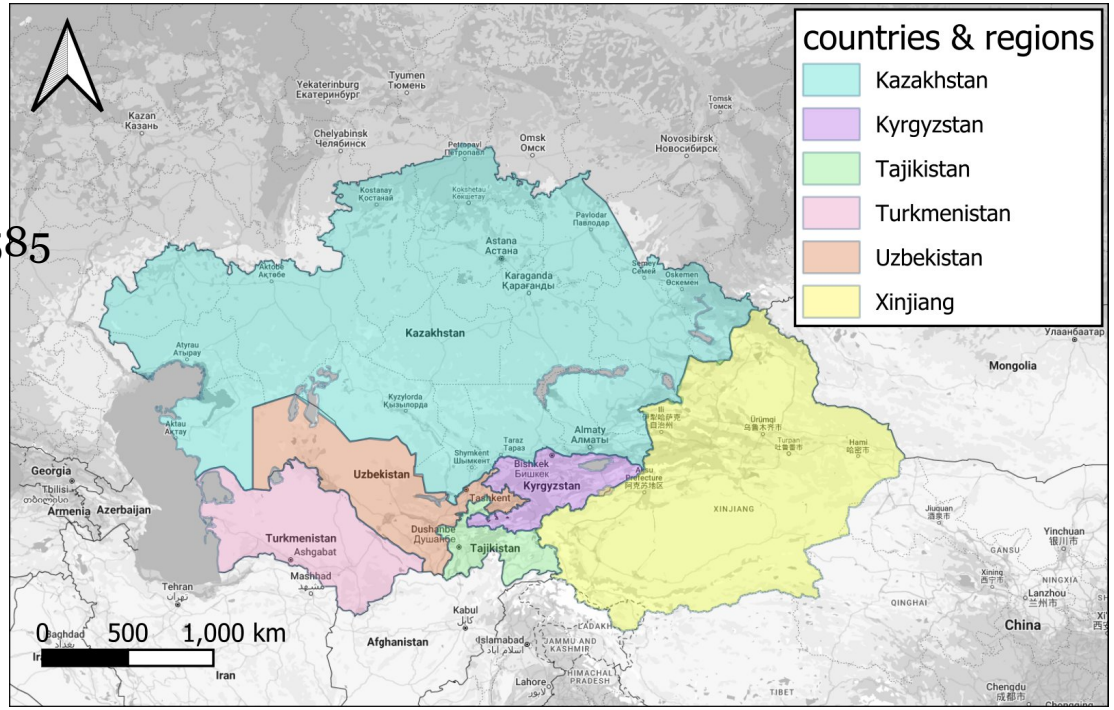
- Novel Self-Evolutionary Complex Network Approach
- Dynamic cross-spatiotemporal scale interaction

ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

Datasets

ISIMIP3b

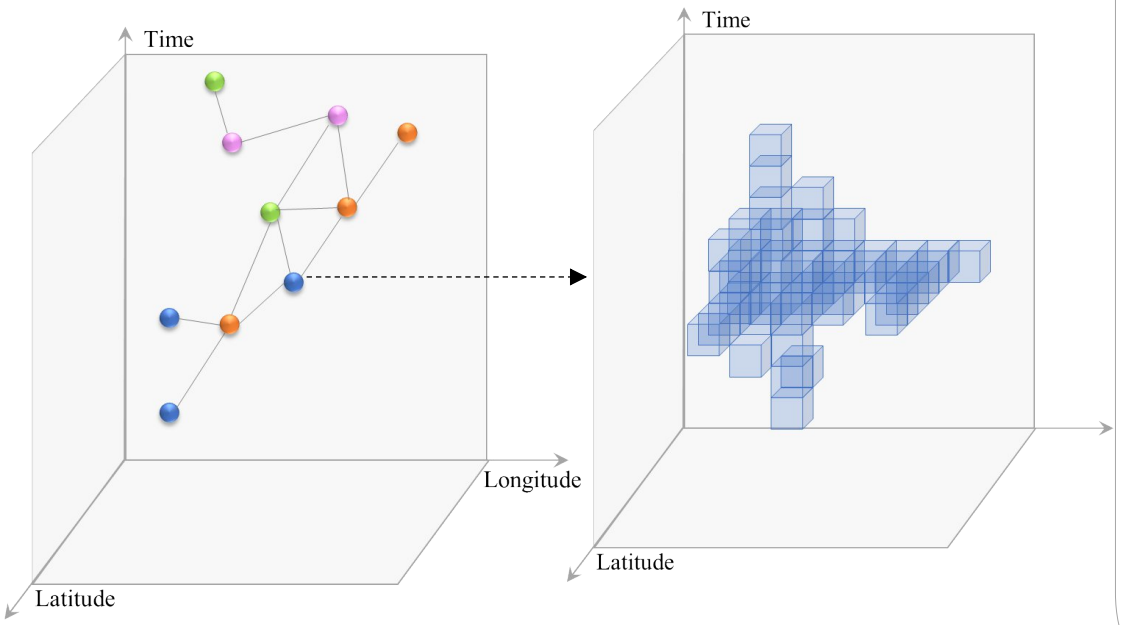
- **GCM:** GFDL-ESM4---- Precipitation (PCP)
- **HM:** WaterGAP2-2e--- Total runoff (Runoff)
- **Study period** : 1980 – 2100--- SSPs 126, 370, and 585
  - ✓ Historical: 1985-2015
  - ✓ Near Future: 2015-2045
  - ✓ Far Future: 2065-2095
- **Study area:** Central Asia



ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

Methodology

Novel Self-Evolutionary Complex Network

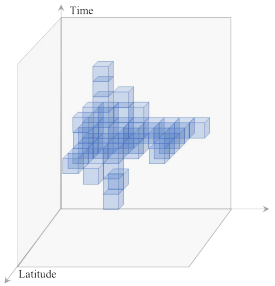


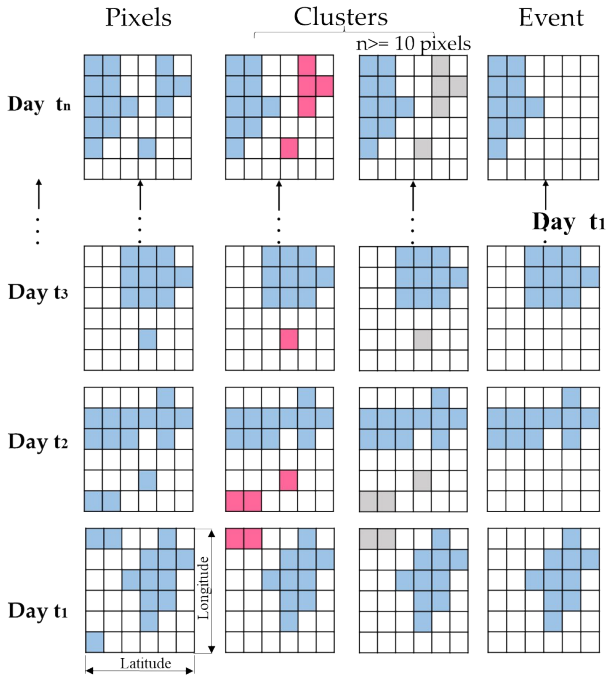
1. Nodes- 3D drought events

a) Drought pixels: *SPI, SRI*

b) Drought cluster

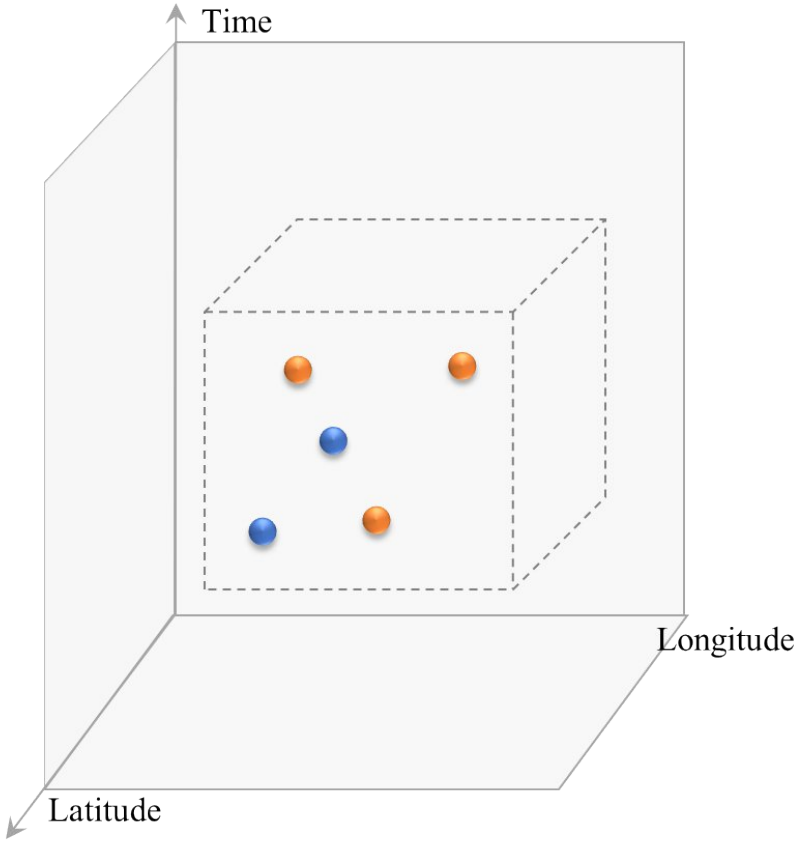
c) Drought events





ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

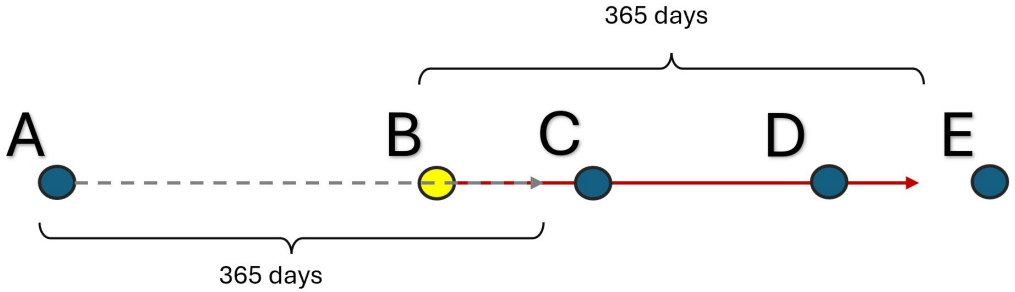
Methodology



2. Linkage-- Boundary

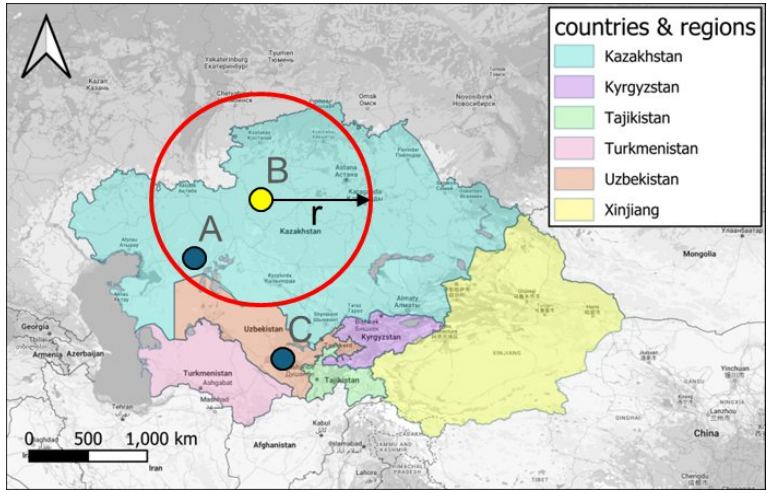
a) Temporal Boundary:

- Up to 12 months between Precipitation and Runoff Drought



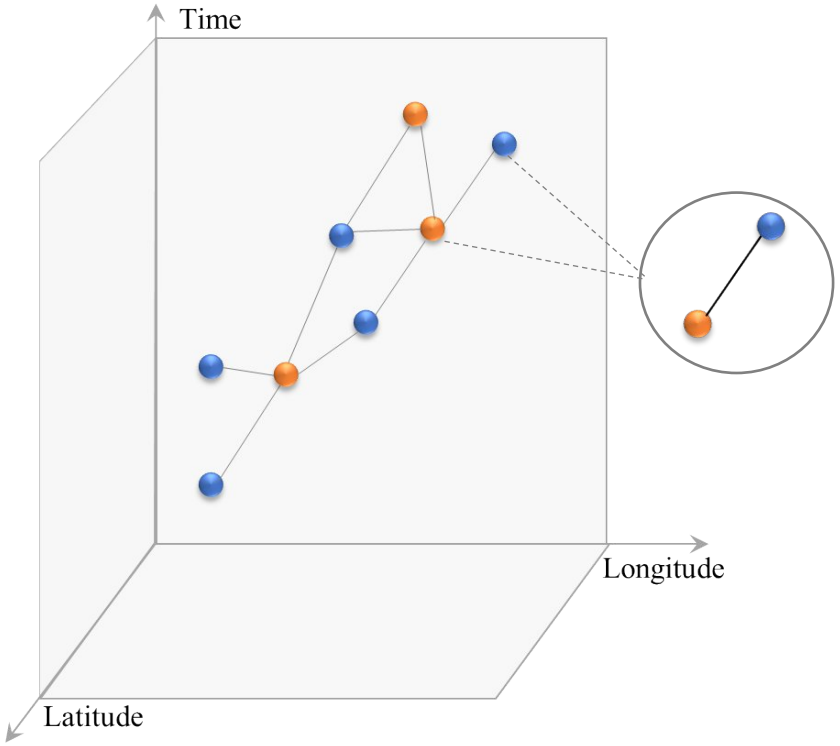
b) Spatial Boundary:

$$r = \sqrt{\frac{0.2 * Total\_Area}{\pi}}$$



ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

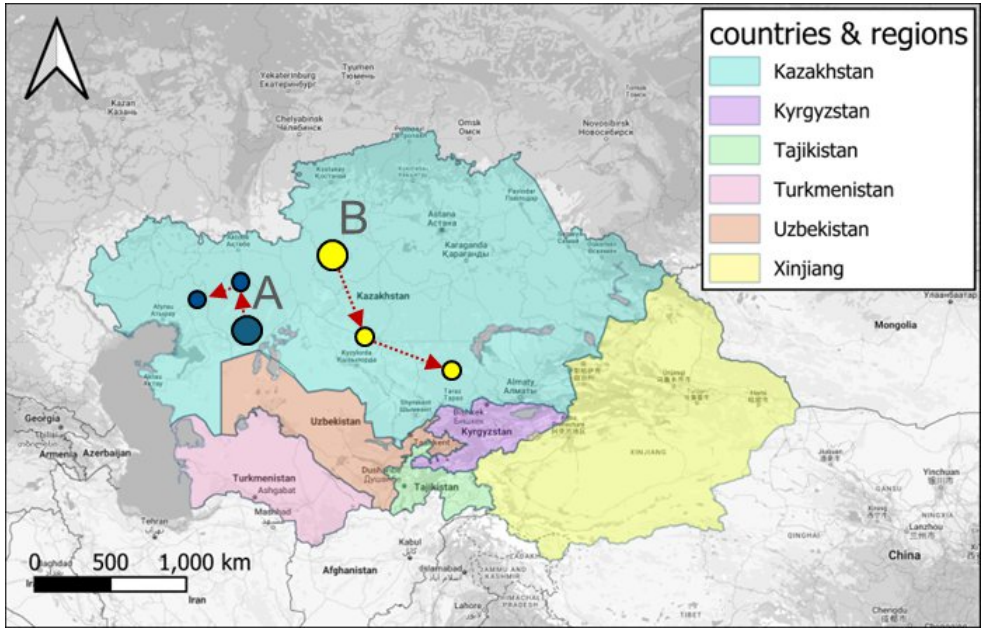
Methodology



2. Linkage- spatiotemporal progression similarity

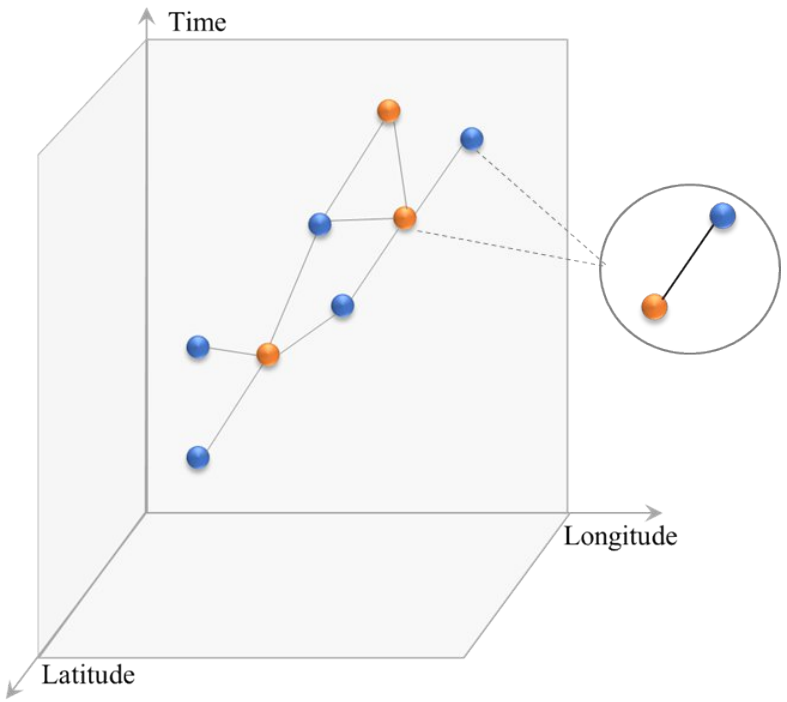
Criterion 1: **Difference in movement direction:**

$$\Delta Direction_{Start-Max} \leq \pm\ 45°$$
$$\Delta Direction_{Max-End} \leq \pm\ 45°$$

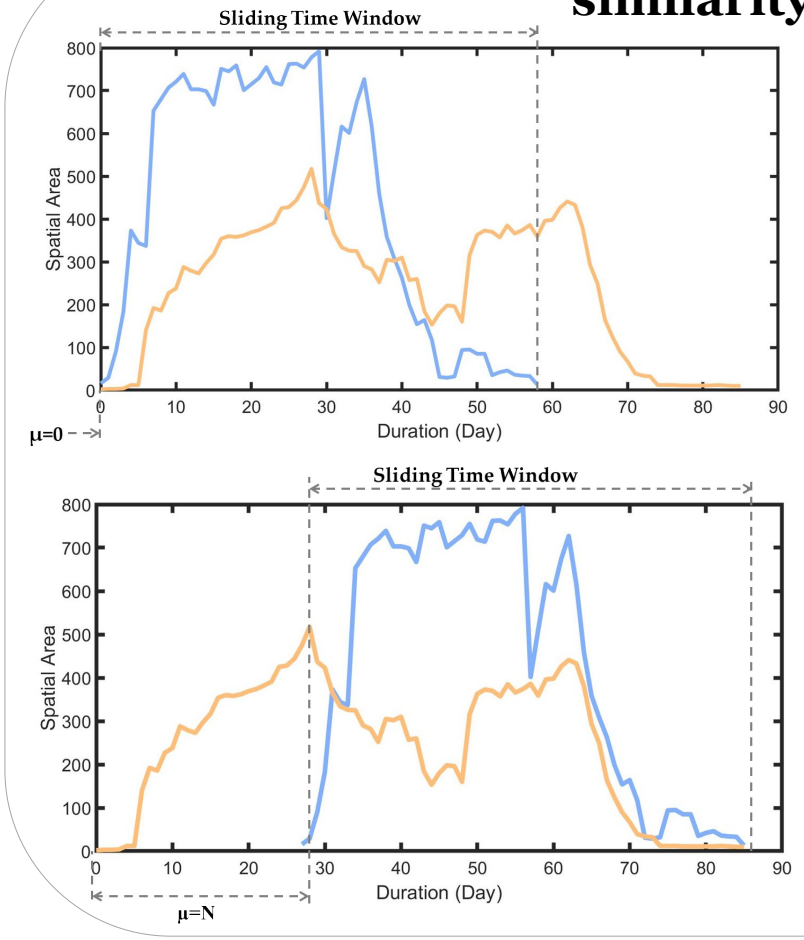


ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

Methodology



2. Linkage- spatiotemporal progression similarity



Criterion 2: Area correlation

- **The daily area variation**
- **Detrended cross-correlation method (DCCA)**
- **Detrended fluctuation analysis (DFA)**

- The time delay is calculated by the **actual time lag where the correlation measured by DCCA exceeds 0.5** between PCP droughts and the corresponding runoff drought events.

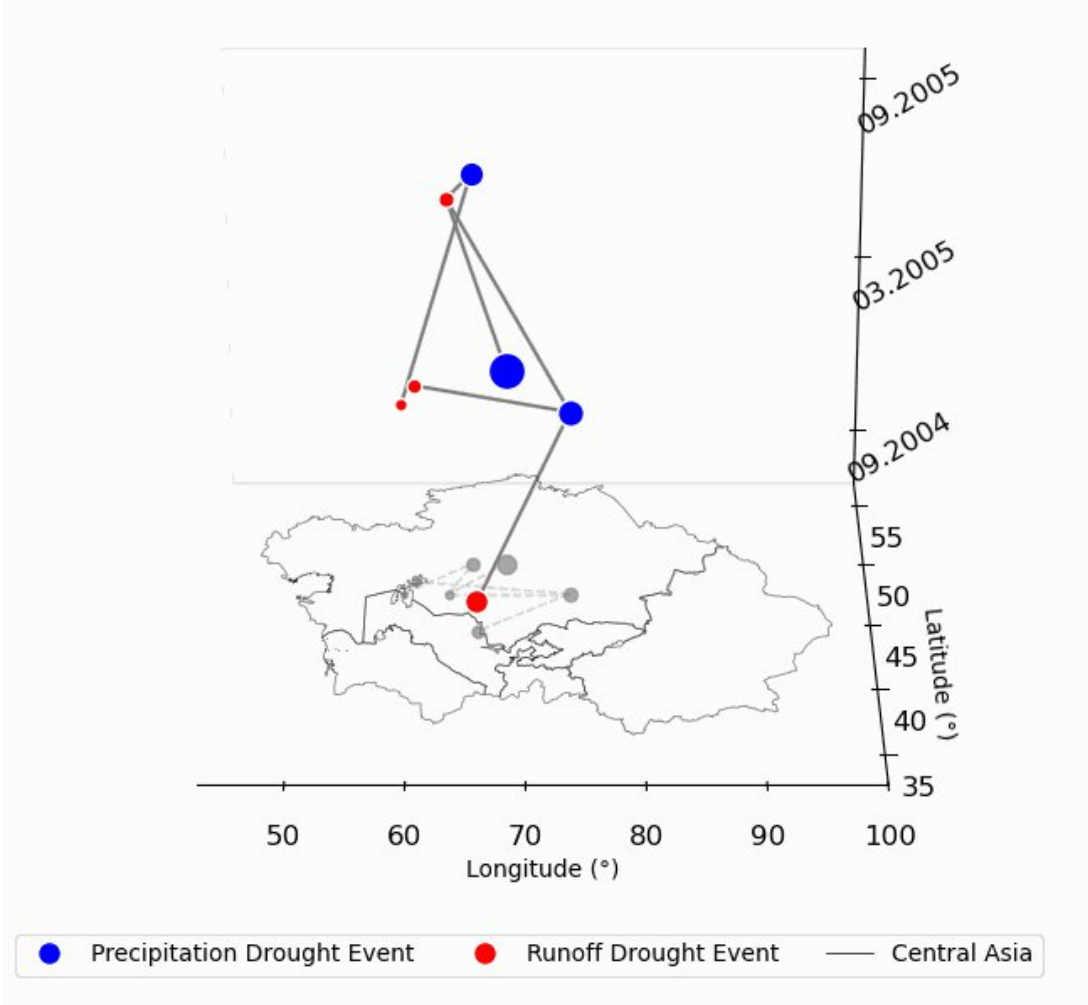
ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

Methodology

1. ***Nodes-3D drought events***
    a) Drought pixels: *SPI, SRI*
    b) Drought cluster
    c) Drought events

2. ***Linkage***
    a) Temporal Boundary:
    b) Spatial boundary:
    c) Propagation direction:
    d) Area correlation:

3. ***Network Construction***

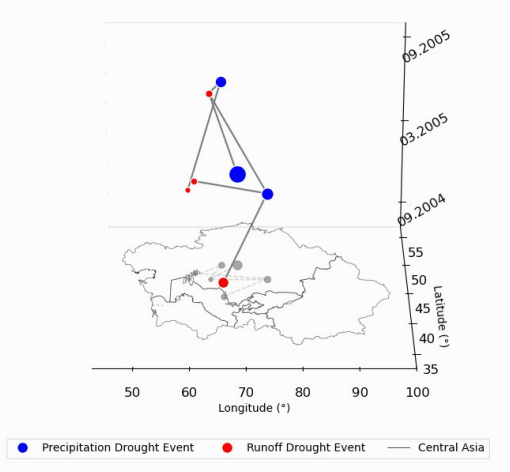


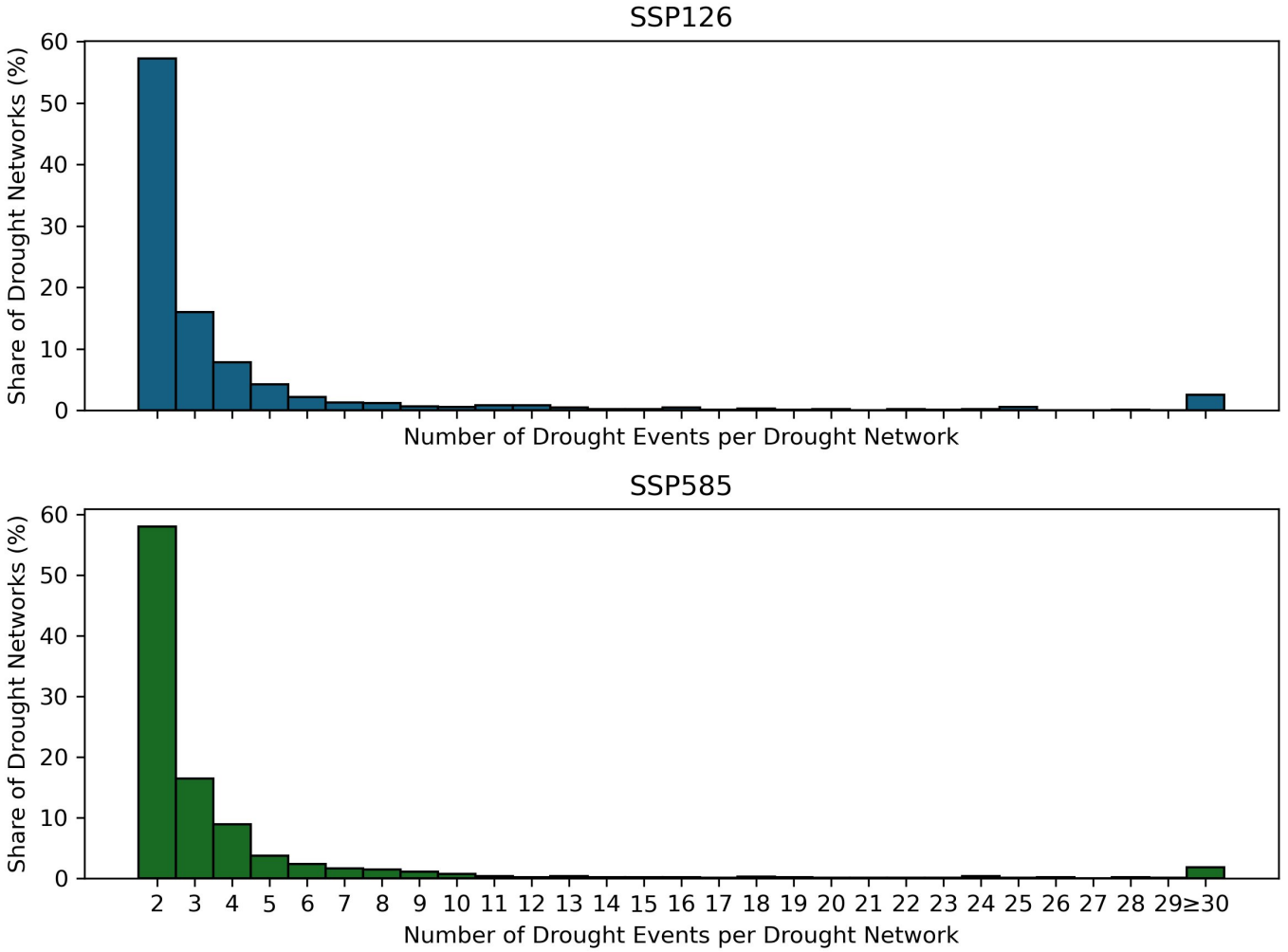
ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

Preliminary result

- Number of cross-system drought Continnum:

  SSP126: 953
  SSP 585: 971

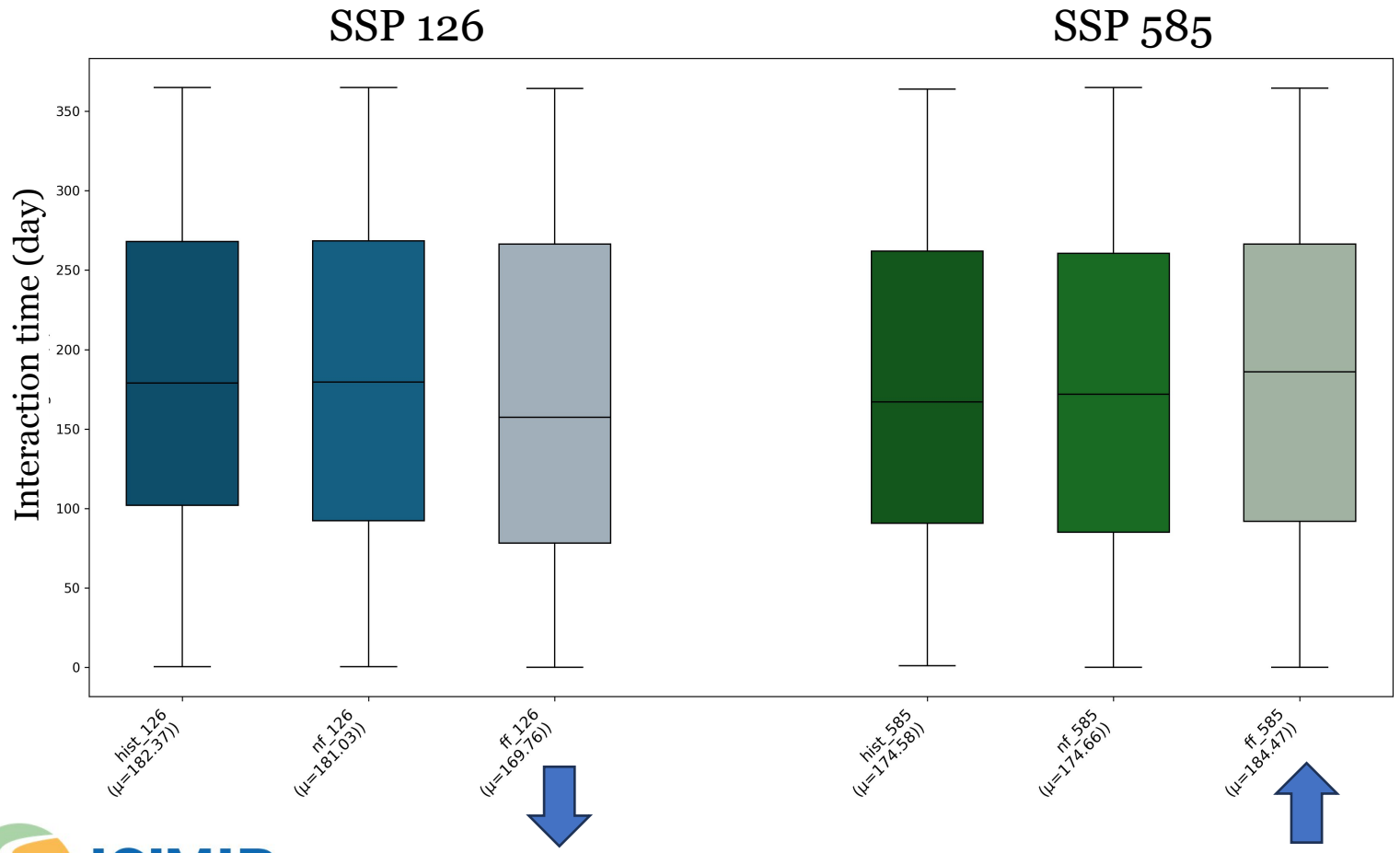


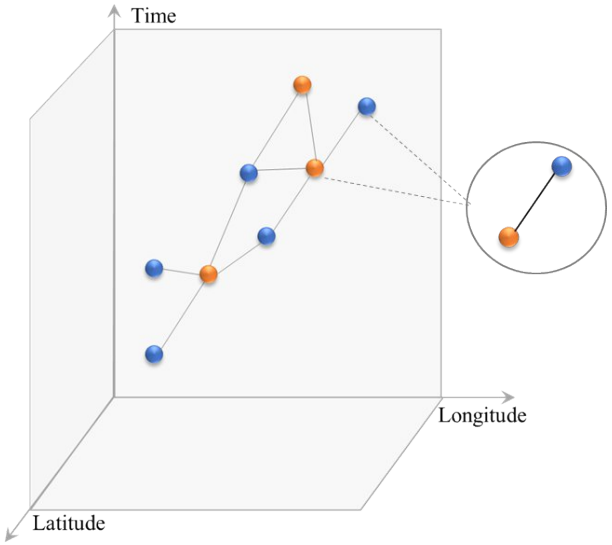


ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

Preliminary result

- Interaction time in the cascading drought continuums





Historical: 1985-2015

Near Future: 2015-2045

Far Future: 2065-2095

ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

Conclusion and Outlook

- Novel Self-Evolutionary Complex Network Approach
  - Long-range cross-spatiotemporal interactions
  - Dimension reduction

- Drought Continnum:
  - More drought continnums in SSP585 compared to the SSP126.
  - SSP126: **Acceleration** of **cascading interactions reflected by the shorter interaction time**
  - SSP585: **Deceleration** of **cascading interactions**

Plan at the next stage:

- Cross-multiple sectors
- Further quantification of dynamic cross-spatiotemporal scale interaction

ISIMIP
Inter-Sectoral Impact Model Intercomparison Project

Thanks for your attention !