Hydrological drought extents in a warming world in large Alpine river basins

Joren Janzing[1,2,3], Niko Wanders[4], Paul C. Astagneau[1,2,3] and Manuela I. Brunner[1,2,3]

[1]WSL Institute for Snow and Avalanche Research SLF, Davos Dorf, Switzerland
[2]Institute for Atmospheric and Climate Science, ETH Zurich, Zurich, Switzerland
[3]Climate Change, Extremes and Natural Hazards in Alpine Regions Research Center CERC, Davos Dorf, Switzerland
[4]Department of Physical Geography, Utrecht University, Utrecht, the Netherlands

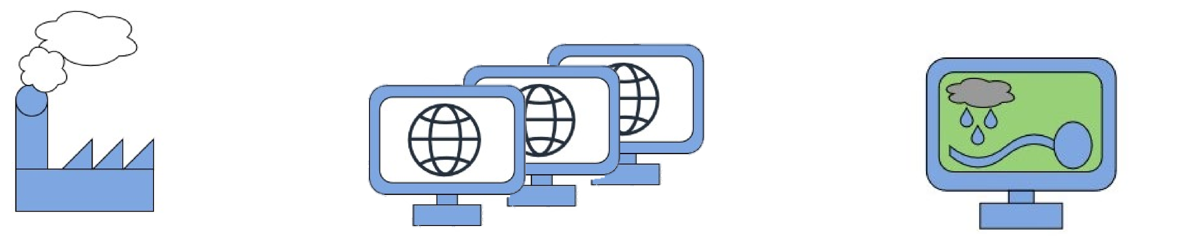
Sharing not permitted

Contact:
joren.janzing@slf.ch

1. Introduction

- **Climate change** affects hydrological drought characteristics such as **severity,** but also **drought extent and low flow timing**
- Many climate impact studies focus on **local changes** in droughts, **rather than drought spatial extent**
- However, **drought spatial extent** is important for **drought impacts and drought relief** (e.g. Murgatroyd and Hall, 2020)
- **"How will spatial synchrony changes affect hydrological drought extent under climate change?"**

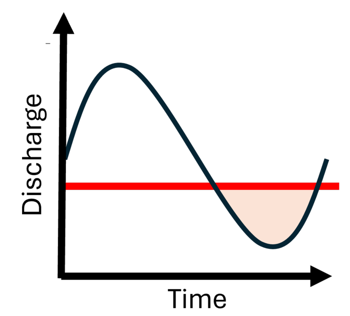
2. Methodology



Emission scenario	Climate ensemble	Hydrological model
RCP8.5 (1989-2099) Reference (Ref): 1991-2020 Global Warming Level 3°C (GWL3): 2035-2064	Bias-corrected ClimEx (Leduc et al., 2019) currently: 6 member subset (Sikorska-Senoner et al., 2024)	PCR-GLOBWB2.0 (Sutanudjaja et al., 2018) 30-arcsec resolution Large Alpine basins of the Rhine, Rhône, Danube and Po rivers

Drought

Fixed threshold levels from low flow GEV distribution. Minimum duration of 30 days.



Drought coherence score (DCS)

(based on Cooper et al., 2025)

- Measures **drought synchrony**
- Split into sub-basins and river branches:

  "if there is a drought in this river branch, which fraction of river branches in a basin also experience drought?"

  (at least 50% event overlap; Gesualdo et al., 2024)
- Average DCS over all events in each river branch

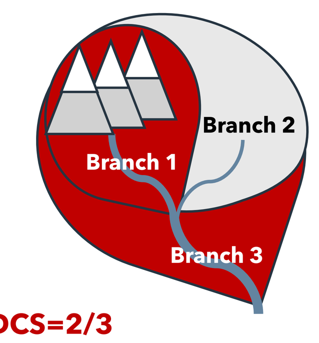
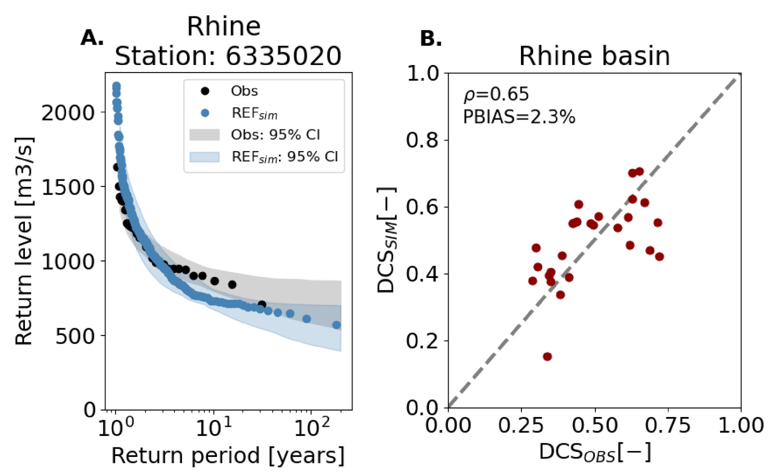


Fig. 1 (right)
Comparison of ensemble of model simulations against observations from the GRDC dataset for the Rhine basin over the reference period. (A) Low flows and return periods for the most-downstream discharge station and (B.) the 1-year drought synchrony for the larger rivers in the basin (Q>100m³/s). CI=confidence interval, ρ=Spearman correlation, PBIAS is percent bias.



3.Hydrological drought synchrony changes depend on threshold level

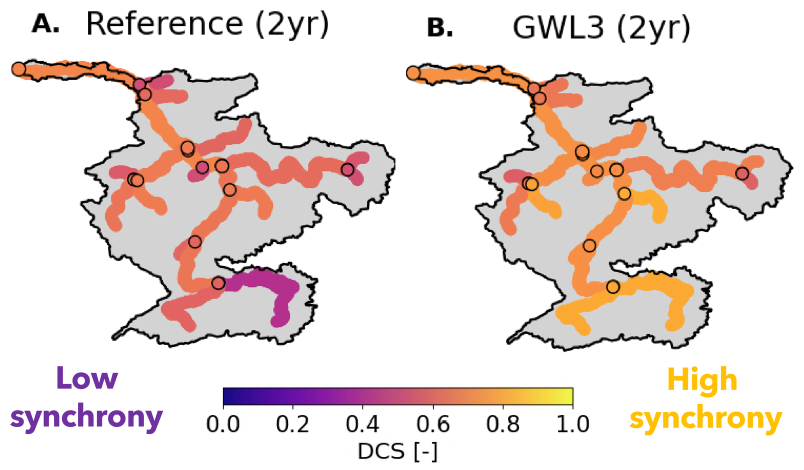
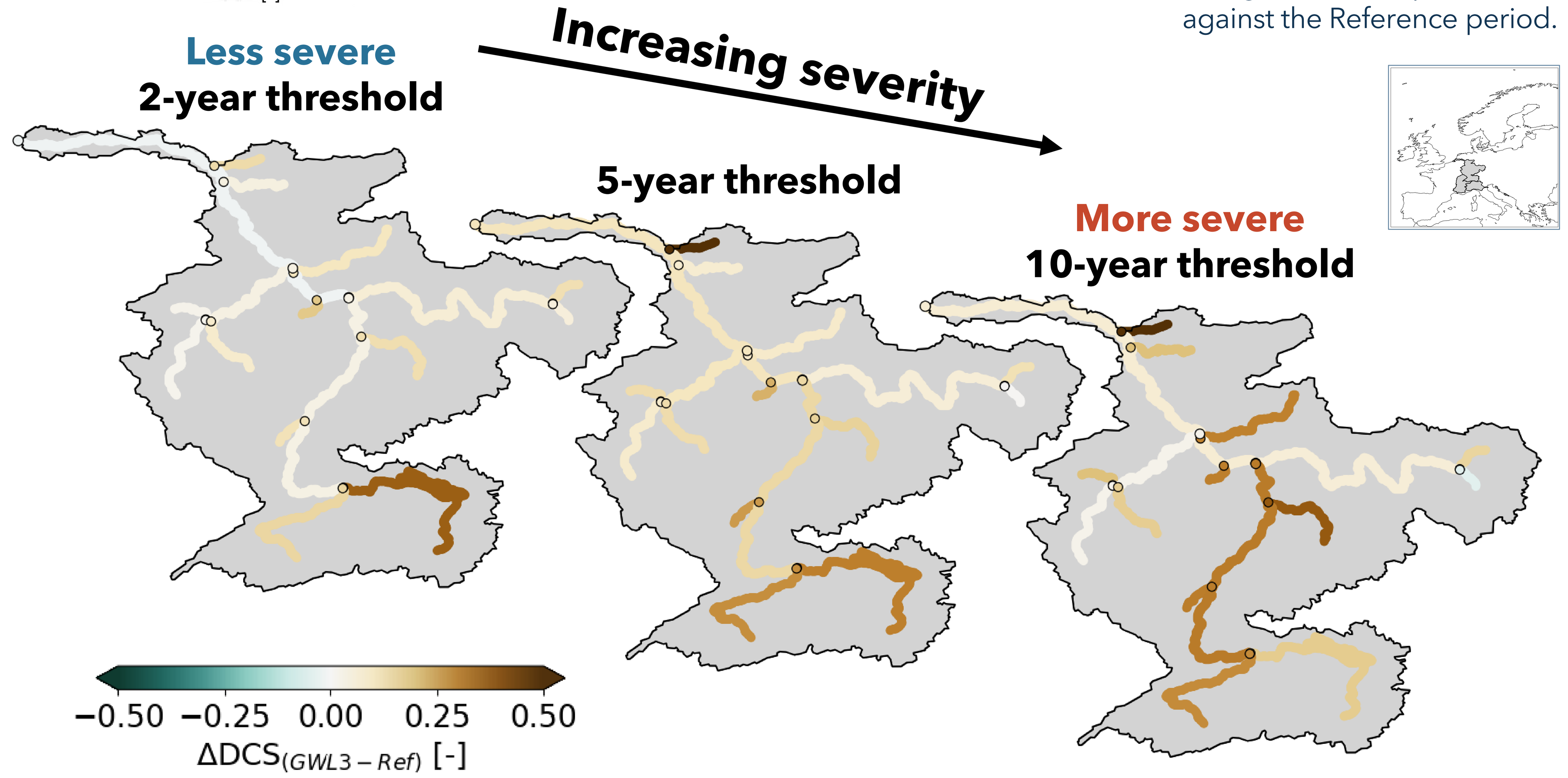


Fig. 2 (left)
Within basin hydrological drought coherence scores for the Rhine basin for a 2-year threshold, showing the Reference (A) and GWL3 (B) periods.

Rhine basin

Fig. 3 (bottom left)
Change in hydrological drought coherence scores (DCS) for the Rhine basin.
We show a 2-year threshold (left), 5-year threshold (middle), and a 10-year threshold (right). We compare GWL3 against the Reference period.



4. Hydrological drought synchrony changes not explained by meteorological drought synchrony only

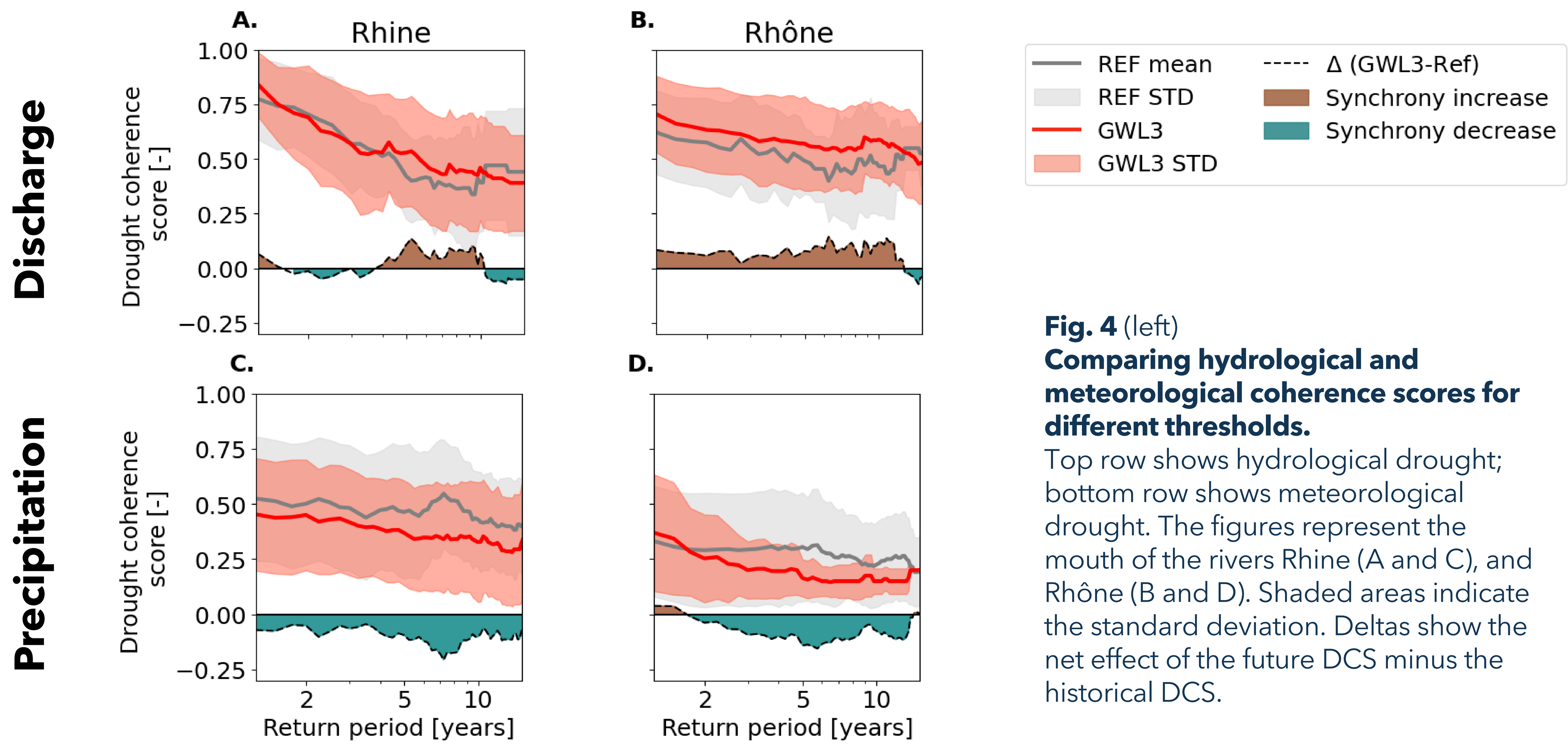
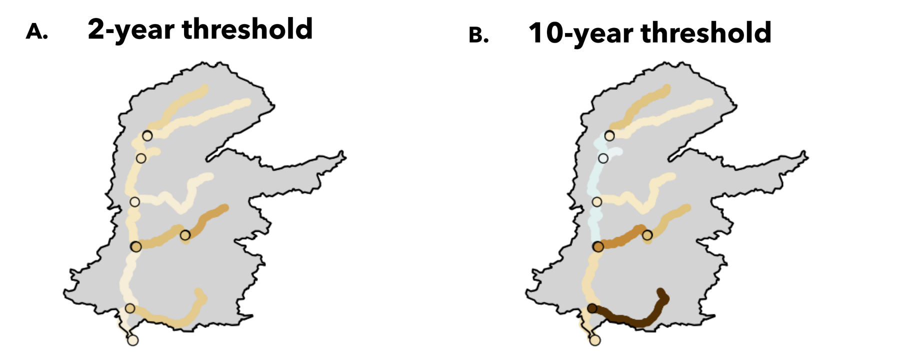


Fig. 4 (left)
Comparing hydrological and meteorological coherence scores for different thresholds.
Top row shows hydrological drought; bottom row shows meteorological drought. The figures represent the mouth of the rivers Rhine (A and C), and Rhône (B and D). Shaded areas indicate the standard deviation. Deltas show the net effect of the future DCS minus the historical DCS.

5. Other basins show similar patterns

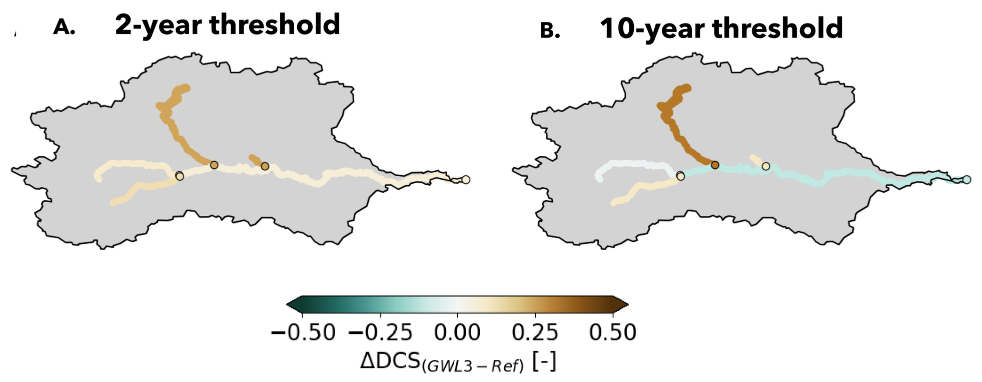
Rhône basin

Fig. 5
Change in hydrological drought coherence scores for the Rhône basin.
We show the difference between GLW3 and the Reference period for the 2-year (A) and 10-year (B) threshold.



Po basin

Fig. 6
Change in hydrological drought coherence scores for the Po basin.
A and B as in Figure 5.



6. Conclusions

- Hydrological drought synchrony is **changing under climate change** as low flow extremeness and regimes are shifting
- Hydrological drought synchrony changes **depend on threshold level**
- Hydrological drought synchrony **does not follow** directly from meteorological drought synchrony
- **Water management should not only focus on local drought evolution, but also on changes in synchrony and drought extent**

7. Open questions

- What happens to **synchrony between basins**?
- Can we **separate** the synchrony changes from changing **frequency** and **severity**?
- How does synchrony depend on **drivers** and **season**?

References

Cooper, M. G., Sun, N., Wigmosta, M. S., Eldardiry, H., Deb, M., Yang, Z., & Judi, D. R. (2025). Enhanced flood synchrony and downstream severity in the Delaware river under rising temperatures. *Communications Earth & Environment*, *6*(1), 296.
Gesualdo, G. C., Benso, M. R., Mendiondo, E. M., & Brunner, M. I. (2024). Spatially compounding drought events in Brazil. *Water Resources Research*, *60*(11), e2023WR036629.
Karger, D. N., Conrad, O., Böhner, J., Kawohl, T., Kreft, H., Soria-Auza, R. W., ... & Kessler, M. (2017). Climatologies at high resolution for the earth's land surface areas. *Scientific data*, *4*(1), 1-20.
Leduc, M., Mailhot, A., Frigon, A., Martel, J. L., Ludwig, R., Brietzke, G. B., ... & Scinocca, J. (2019). The ClimEx project: A 50-member ensemble of climate change projections at 12-km resolution over Europe and northeastern North America with the Canadian Regional Climate Model (CRCM5). *Journal of Applied Meteorology and Climatology*, *58*(4), 663-693
Murgatroyd, A., & Hall, J. W. (2020). The resilience of inter-basin transfers to severe droughts with changing spatial characteristics. *Frontiers in Environmental Science*, *8*, 571647..
Sikorska-Senoner, A. E., Rajczak, J., Zappa, M., & Kotlarski, S. (2024). User-tailored sub-selection of climate model ensemble members for impact studies. *Science of the Total Environment*, *952*, 175769.
Sutanudjaja, E. H., Van Beek, R., Wanders, N., Wada, Y., Bosmans, J. H., Drost, N., ... & Bierkens, M. F. (2018). PCR-GLOBWB 2: a 5 arcmin global hydrological and water resources model. *Geoscientific Model Development*, *11*(6), 2429-2453.