



Storyline-based climate attribution reveals strong intensification of 2018-2022 multi-year droughts in Europe

Ray Kettaren¹, Antonio Sanchez-Benitez², Helge Goessling², Marylou Athanase², Rohini Kumar³, Luis Samaniego^{3,4}, and Oldrich Rakovec¹

¹Czech University of Life Sciences Prague (CZU), Faculty of Environmental Sciences (FZP), Department of Water Resources and Environmental Modeling, Praha - Suchbát, Czechia (kettaren@fzp.czu.cz)

²Alfred Wegener Institute, Helmholtz-Centre for Polar and Marine Research, Bremerhaven, Germany

³UFZ-Helmholtz Centre for Environmental Research, Leipzig, Germany

⁴Institute of Environmental Science and Geography, University of Potsdam, Potsdam, Germany

Prolonged summer droughts represent a significant and growing threat across Europe, as their persistence hinders hydrological recovery and severely impacts water resources, ecosystems, and agricultural systems under ongoing climatic warming. These extended dry periods can create soil-moisture deficits, ecological stress, and amplified heat extremes. Understanding the response of multi-year droughts to different warming levels is vital for shaping both adaptation and mitigation strategies.

In this study, we investigate the behaviour and severity of the 2018-2022 European multi-year soil moisture drought across a range of climate warming levels. We apply an innovative storyline attribution approach, which enables a physically consistent comparison of the same drought sequence under different climate conditions. Specifically, we utilise spectrally nudged AWI-CM-1-1-MR, constrained to follow observed synoptic-scale circulation from ERA5, to force the mesoscale Hydrologic Model (mHM). This modelling setup allows us to specifically isolate how anthropogenic warming modifies soil-moisture deficits, without altering the real-world atmospheric conditions that triggered the drought sequence.

Under the present-day climate conditions, the 2018-2022 drought produced a soil-moisture deficit of $-44 (\pm 11.8) \text{ km}^3$, affecting $0.63 (\pm 0.07)$ million km^2 (11.5% of the study area). In the absence of anthropogenic climate change (pre-industrial climate conditions), the 2018-2022 multi-year event would have shown a soil moisture surplus nearly double the magnitude of present-day losses, with drought spatial extent only about one-third of current levels. Future warming levels further exacerbate these impacts. With warming of 2 K to 4 K, the losses increase from $-82 (\pm 6.6)$ to $-256 (\pm 7.1) \text{ km}^3$, while drought extent expands from approximately 16% to 43%.

Overall, our results demonstrate that rising global temperatures substantially intensify multi-year droughts by both enlarging their spatial footprint and deepening hydrological deficits. As climate warming increases the likelihood that single-year droughts transition into persistent multi-year events, the findings emphasise the urgent need for effective climate mitigation and adaptation

strategies across Europe. A full version of this work is currently under review in *Journal of International Business Studies*; the preprint can be accessed at <https://doi.org/10.22541/au.176220208.89936181/v1> .