Project: **1445**
Project title: **Breathing Nature – Connecting biodiversity, climate, and human behavior**
Principal investigator: Sebastian Sippel
Funding: Sächsisches Staatsministerium für Wissenschaft, Kultur und Tourismus (SMWK) / Submitted DFG Cluster of Excellence
Reporting period: **2024-07-01 to 2025-06-30**

Summary of project goals of Breathing Nature (BN):

The **Breathing Nature project** seeks to establish a comprehensive understanding of the interconnected dynamics between climate change, biodiversity, and human behavior. The research program focuses on three main areas:
Connectivity: Investigating mechanisms that link biodiversity, climate, and human activity.
Agency and Responsibility: Examining human influence on climate and biodiversity.
Alternative Futures: Modeling sustainable future scenarios integrating climate, biodiversity, and human factors. The sub-project **Agency and Responsibility** currently requires climate modeling with CESM2 to conduct attribution studies across these domains. Using both factual and counterfactual simulations, Breathing Nature/Agency and Responsibility aims to assess human impacts on climate and ecosystems (incl. biodiversity) across various subprojects, leveraging DKRZ resources to simulate climate attribution scenarios to causal drivers.

Resource use in the past reporting period:
Since July 2024, Breathing Nature has utilized computational resources primarily to establish and validate model configurations. Initial CESM2 simulations on Levante were conducted to verify compatibility and performance, which is the basis for full-scale simulations that have been conducted in the following months.
Total Resource Use: Approximately 45501node hours and 67 TB of storage utilized as of 2025-04-23. We used all the granted resources, and we would therefore like to apply for new allocation of resources.

We describe the state of the simulations in more detail below (some of these simulations are carried out in synergy with our contribution to the climXtreme II / PATTETA project):

- **Circulation nudging experiments in CESM2**

Within the reporting period, we conducted several large-scale CESM2 simulations as part of our storyline attribution framework. Our research focused on two primary experiments spanning the observational period from 1940 to 2024:

1. **Historical CO2 Experiment ("HIST")**: This experiment employed historical CO2 concentrations without incorporating CO2 fertilization effects. The results from this experiment allowed us to differentiate the thermodynamical effects of climate change from biological responses.
2. **Constant Climate Forcing Experiment ("NAT"):** In this experiment, we applied constant climate forcing based on the year 2024 throughout the entire simulation period.

In addition, we simulated a CO2-only plant fertilization scenario, and a "high CO2" scenario. We assessed the circulation nudging method's accuracy in reproducing climatic anomalies and carried out analyses within the attribution framework. **The results are very interesting from a scientific view, because they demonstrate that a large fraction of up to 50% (depending on the variable considered) of European summer hydroclimate/drought trends over the past decades have been**

driven by changes in atmospheric circulation. A draft manuscript (Dunkl et al., 2025, in prep.) is in preparation and will be submitted in due course.

- **CESM2 ensemble for boosting and/or importance sampling**

We completed a 42-member CESM2 (fully coupled) ensemble for 2021–2031, representing current climatic conditions. Additionally, a 450-year CESM2 piControl simulation was conducted. This current climate ensemble, along with the piControl run, will support ensemble boosting and importance sampling experiments, enabling comparisons between current and pre-industrial climates. While similar ensembles exist, re-simulation on Levante was necessary to ensure bitwise reproducibility, critical for precise ensemble boosting. The ensemble was largely calculated with resources from the climXtreme II project, but it will be the basis for the importance sampling experiments that we are planning as part of the BN project.

- **CESM2 importance sampling experiments**

In the past three months of the reporting period, we have conducted importance sampling experiments using a rare event algorithm (Ragone and Bouchet, 2021, *Geophysical Research Letters*, doi:10.1029/2020GL091197). This algorithm allows to analyse worst-case simulations, and within the BN project we are analyzing potential worst-case years for the European ecosystem carbon balance. This is a highly policy-relevant topic, as the European natural carbon sink is used for carbon accounting, and European natural carbon sinks have declined in recent years. These simulations are currently running on Levante.

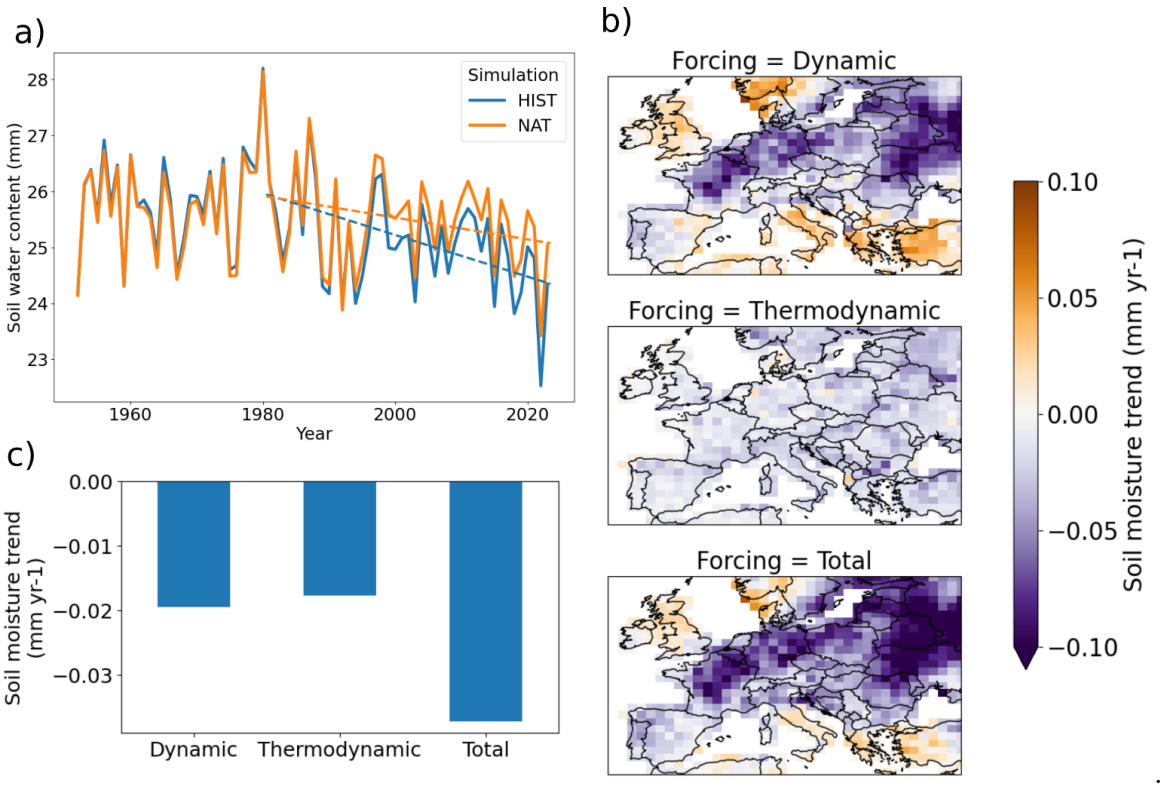

Figure 1: Multi-decadal dynamical and thermodynamical trends in JJA 10 cm soil moisture over Europe (1980 - 2023). a) The absolute soil moisture values in the historical (HIST) and pi-Control (NAT) simulations. b) The spatial patterns of the total (HIST), dynamical (NAT) and thermodynamical (HIST - NAT) trends. c) Shows the absolute contribution of the trends over the whole domain. Reference: Dunkl et al., 2025, in preparation.