Sustainable Pathways under Climate Variability

Kira Rehfeld¹ and the SPACY research group members*
¹Tübingen University, Department of Geoscience and Department of Physics, Germany
* A full list of authors appears at the end of the abstract

External forcings and feedback processes of the Earth system lead to timescale and state-dependent climate variability, causing substantial surface climate fluctuations in the past. Particularly relevant for future livelihoods, changing variability patterns could also modify the occurrence of extreme events. However, spatiotemporal mechanisms of climate variability are poorly understood. Likewise, the societal implications are weakly constrained, particularly variability's potential to drive sustainable transformation. The SPACY project investigates climate variability from past cold and warm periods to future scenarios. One research focus is how forcing mediates climate fluctuations. Bridging the gap between Earth system models and palaeoclimate proxies, we study vegetation and water isotope changes. A second focus is exploring sustainable pathways under climate variability, addressing potential interactions between artificial carbon dioxide removal and surface climate, among others.

In particular, we validate the ability of climate models to represent potential climate variability changes. Here, we focus on isotope-enabled simulations with dynamic vegetation. We find that models exhibit less local temperature and water isotope variability than paleoclimate proxies on decadal and longer timescales. Simulations with natural forcing agree much better with proxy records than unforced ones. The mean local temperature variability decreases with warming. Furthermore, we analyze potentials and limitations of terrestrial hydroclimate proxies. This includes water isotopes in speleothems and ice cores and vegetation indicators derived from pollen assemblages.

Transferring our understanding to the future, we contribute to mitigation and sustainable transitions. Weather and climate extremes determine losses and damages, but their impact on socioeconomic development is poorly examined. We scrutinize damage parametrization of economic models regarding the ability to consider variability. While large-scale sequestration of atmospheric carbon dioxide is paramount to mitigation targets, its representation in climate models is insufficient. Accounting for feedbacks of carbon dioxide removal (CDR) requires model experiments with modified land surfaces. We develop CDR representations of “artificial photosynthesis” in Earth system models. Pollen records benchmark the simulated climate–carbon dioxide–vegetation interactions. This supports modeling endogenous societal land use decisions in the future.
Our work continues to improve the understanding of long-term climate predictability. The combined knowledge from past climate studies and comprehensive modeling for future scenarios underlines the relevance of changing boundary conditions for a future within planetary boundaries.

**SPACY research group members:** Kira Rehfeld, Moritz Adam, Jean-Phillipe Baudouin, Laura Braschoß, Janica Bühler, Mathurin Choblet, Beatrice Ellerhoff, Olga Erokhina, Laura Fink, Johannes Grabenstein, Jakob Kruse, Markus Maisch, Valdir F. Novello, Felix Pollak, Muriel Racky, Magdalena Ritzau, Leoni Rath, Nabeela Sadaf, Arya Samanta, Yana Savytska, Sonja Spälter, Stephan Sprinz, Irene Trombini, Daniele Voglis, Nils Weitzel, Elisa Ziegler, Mitja Ziegler