Project: **1343**
Project title: **SCENIC-DynAI – AI supported climate model downscaling for storyline-based impact analyses**
Principal investigator: **Benjamin Fersch**
Report period: **2024-11-01 to 2025-10-31**
Maximum of 2 pages including figures. 9 pt minimum font size.

Project overview

As part of the Helmholtz Innovation Pool of the Research Field Earth and Environment project SCENIC (Storyline Scenarios of Extreme Weather, Climate, and Environmental Events along with their Impacts in a Warmer World) the objective of the SCENIC-DynAI subproject is to develop artificial intelligence supported regionally downscaled storyline-based climate simulations for Central Europe and Germany and the generation of dynamically downscaled simulations for the project consortium. Within SCENIC, global simulations are being generated (DKRZ project 1264: Storyline simulations of extreme events with spectral nudging) for a specific period (2014-now) by applying spectral nudging of atmospheric winds (particularly the jet stream) in a storyline approach for different climate scenarios. The overall objective is to investigate the possible manifestations of real-world present-day extreme weather (heat-waves, droughts and heavy rain) under pre-industrial, present day, +2K, +3K, and +4K conditions.

The SCENIC-DynAI project wants to develop an alternative AI-based downscaling method and test it for climate impact modeling. Therefore, it has 2 major objectives: 1) to create a set of dynamically downscaled storyline based global climate simulations as a comparison benchmark for within the project prepared machine learning based downscaling products and for climate impact studies within the project consortium of SCENIC, 2) to train generative adversarial fourier neural operator networks for a AI/ML based bias correcting and downscaling of the global model runs.

Report for allocation period 2025

Dynamical downscaling

In 2025 the dynamical downscaling of the 3 km ICON simulations to 1 km WRF with local climate zones and 10 class Urban scheme was continued. The post-processing of the simulations revealed some structural problems with the Urban model in one domain which is still matter of investigation. Due to performance issues with Levante, several netcdf output files contained HDF errors which required some reruns for shorter periods. In addition, recently found errors in the forcing data from the global AWI climate model that have been now corrected will require a rerun of a smaller portion of the simulations.

The significantly reduce computational resources for the past allocation period disallowed the simulation of the variability in the downscaled storyline scenarios. The reduced storage amount considerably increased the effort to continue the simulations as there was not enough space to pre-process the forcing data and run the 5 scenarios and the 2 domains simultaneously. Within the remaining period of 2025 the yet complete simulations will be transferred to the long-term archive (DOKU).

AI-based downscaling

During the allocation period 2025, the development of the deep learning based downscaling model spateGAN [1] was successfully advanced to spateGAN-ERA5 [2]. This represents the first model capable of downscaling global ERA5 precipitation to kilometer and sub-hourly scales, with a computational efficiency producing precipitation maps within 2 seconds using 4 A100 GPUs.

The originally proposed experiment to further improve model performance by including orographic features as model input proved not to be beneficial. We instead focused on a comprehensive transferability study across diverse climatic regions, including tropical rainfall regimes in northern Australia. The results were published in June 2025 in npj Climate and Atmospheric Science. The model was released on GitHub (https://github.com/LGlawion/spateGAN_ERA5) and the dataset published on zenodo [3], supporting open-access research.

As the main focus was on publication and model evaluation, not all allocated GPU resources were fully utilized.

[1] Glawion, L., Polz, J., Kunstmann, H., Fersch, B., & Chwala, C. (2023). spateGAN: Spatio-temporal downscaling of rainfall fields using a cGAN approach. Earth and Space Science, 10, e2023EA002906. https://doi.org/10.1029/2023EA002906

[2] Glawion, L., Polz, J., Kunstmann, H., Fersch, B. and Chwala, C.: Global spatio-temporal ERA5 precipitation downscaling to km and sub-hourly scale using generative AI. npj Clim Atmos Sci 8, 219 (2025). https://doi.org/10.1038/s41612-025-01103-y

[3] Glawion, L. (2025). spateGAN-ERA5 precipitation downscaling - Datasets. Zenodo. https://doi.org/10.5281/zenodo.17417589