Project: **1343**

Project title: **SCENIC-DynAI – AI supported climate model downscaling for storyline-based impact analyses**

Principal investigator: **Benjamin Fersch**

Report period: **2022-11-01 to 2023-10-31**

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 (2017-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, and +4K conditions.

Report for allocation period 2023

For the first of the two main objectives of SCENIC DynAI, the dynamical downscaling of the global storyline scenarios the experiment setup has changed, partly motivated by the review comments for the last proposal and due to the developments within the SCENIC project. Since the downscaling of the global runs to a 1 km Germany domain would have generated a large computational demand and the project partners would only need the data for some specific regions, it was decided to select 3 domains which together represent about one third of Germany‘s area. Owing to the availability of 3 km regional downscalings from the ICON simulations for Germany within the project (DKRZ project 1264), it was suggested to further refine these 3 km runs for the 3 one km domains with the WRF model. However, delays in the production of the 3 km ICON runs lead also to delays within SCENIC-DynAI. With respect to the amount of so far consumed node hours, this is the main reason why only a small part of the allocated resources have been used. In late spring 23, we developed the methods to convert ICON output to WRF input. In fall we could start to perform some first sensitivity runs with WRF for the northern Germany domains. We tested a bunch of physical parameterizations, mainly for the microphysics (clouds) and the planetary boundary layer. In the coming weeks we will continue these runs for a full year plus 6 months of spinup. And after that, we can start production of the full period (2016 – 2023) which is considered by the SCENIC project. This will create high resolution storyline simulations that will be used in our AI-based downscaling approach and by the project partner for high resolution climate impact studies.

Considering the usage of the allocated GPU resources, investigating objective three of SCENIC DynAI, further investigations of the methological description resulted in deviations from the schedule and objective. In particular, we were not able to present the methodological basis of our planned study, prepared at KIT IMK-IFU, until spring 2023, followed by working on the revision and publication in early fall 2023. Consequently, we focused on AI-based GCM downscaling in late summer.

Since the AWI GCM storylines are able to simulate certain weather events by model nudging and are therefore in moderate to high agreement with observed data, we initially carried out a superresolution AI downscaling approach, based on our findings. The generative model proved to be able to reconstruct a high resolution extreme value distribution and generates rain fields with plausible spatio-temporel structures from low resolution input data.

However, we realized at an early stage that the selected method has two major limitations.

1. the domain restriction of RADKLIM-YW to Germany and the high downscale step (~108 km, 1 hr to 1km, 5 min.) lead to a training patch size limitation of 5x5 pixel. Within these patches was not enough information to let the model adequately learn to generate plausible advecting rain fields.

2. 3D convolution has been proven to be able to generate highly realistic structures, however it has a considerably high GPU memory demand. Even so GCM downscaling was still possible with linear scalability when applying the model to a sequence of patches of different regions, we have the assumption, that a extended receptive field to account for global correlations will be a necessary feature for a high performing AI GCM downscaling model.

Therefore, we did not spent the GPU resources for computationally complex hyperparameter optimizations runs, but instead we small scale tested model structures suitable for exploiting extended spatial and temporal correlations within the data, such as adaptive fourier neural operators, and their applicability for downscaling models. In addition, we have investigated multivariable downscaling with ERA5 data as target variable, which could be performed as a preceding step to the spatio-temporal downscaling to RADKLIM-YW resolution.

In the following weeks, we will complete the foundations for training a generative AI model for downscaling global data in a single processing step and prepare a training- , hyperparameter optimization- and cross validation pipeline. The generated high-resolution storylines will be compared with the results of the ICON and WRF downscaling. Furthermore, we will investigate the model robustness within a non-stationary climate. The results will provide important insights into the potential and applicability of AI methods in climate science, especially for downscaling.