Project: 1264
Project title: Storyline simulations of extreme events with spectral nudging
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Report period: 2023-11-01 to 2024-10-31

As outlined in the project proposal, the goal of this computing project has been to explore the storyline approach with unprecedented detail. In this project, we have continued the workflow developed in the previous project phase, where the global storylines simulations are downscaled into high resolution (EUR011, covering Europe with 12 km resolution, and GER00275, with 3 km grid spacing for Germany). Also, a novel hybrid pseudo-global warming (PGW)/storyline approach has been tested successfully in close collaboration between AWI and KIT**.** In addition, the global runs have been extended backwards and forwards, and new idealised nudging simulations (“perfect-model” type, see description in the previous proposal) have been completed. The computing project is linked to the Helmholtz Innovation-Pool project SCENIC (Storyline Scenarios of Extreme Weather, Climate, and Environmental Events along with their Impacts in a Warmer World), but also external partners have made use of these simulations.
Specifically, the following simulations have been completed using the computational resources allocated this year.

1. Extension of the previous global "Short runs" nudging-based coupled-model storyline simulations using AWI-CM1.
    a. Extension forwards in near-real time with a 3-day delay for pre-industrial, present and +4K climates.
    b. Extension backwards to 1st January 2014 for all climate forcings (pre-industrial, present, +2K, +3K and +4K climates).
2. New idealised global nudging simulations ("perfect-model" type) extending for 35 years.
    a. Cross-climates (pre-industrial winds in end-of-21st century climate and vice versa).
    b. Same climate for winds and thermodynamics.
3. Regional ICON-CLM simulations
    a. Extension of existing EUR011 and GER00275 for ensemble member 1 backward to 1st January 2014 for all climate forcings mentioned in 1b.
    b. Extension from 1 to 5 ensemble members of EUR011 simulations in the period 01/01/2017-30/09/2022 for all climate forcings mentioned in 1b.
4. Hybrid regional PGW/storyline approach. Deltas are computed in the following ways:
    a. Linear 2K, 3K, and 4K temperature perturbations and related specific humidity perturbations based on the Clausius–Clapeyron relation.
    b. Thermodynamic perturbation using vertical level temperature, humidity and skin temperature variables.
    c. Thermodynamic and dynamic perturbation using vertical level temperature, humidity, u and v wind components, surface pressure and skin temperature variables.

The project has achieved significant results, including several scientific publications described in this report.

1. The global runs generated with AWI-CM1 in the previous phases of this project, where the dynamics are fixed (via nudging), and the thermodynamic conditions adapt to different warming targets, were extended backwards (1b) and are being extended forward in "near real-time" (with a 3-day delay, 1a). This extension allows for analysis of a growing time span and rapid assessments, like the attribution of the September 2024 floods in Central Europe (Athanase et al., 2024). We have also developed a web tool to publicly visualise key fields from these experiments through https://climate-storylines.awi.de/. These simulations will also be instrumental in analysing the record-low Antarctic sea ice levels reached in recent years or the recent European drought, including a description of the conditions during the 2015-2022 period, papers in preparation.
2. Idealised global simulations have been conducted introducing a novel approach by imposing end-of-21st century dynamics into pre-industrial thermodynamic conditions and vice versa (2a). Together with simulations where the winds from the same climate but a different ensemble member are imposed via nudging (2b) for pre-industrial and end-of-21st century climates. These 35-year long and 5-ensemble member simulations are now being analysed by a Master’s student to (i) study possible methodological artefacts of the nudging technique and (ii) disentangle dynamic and thermodynamic contributions to climate change systematically, addressing an ongoing controversy. One paper is in preparation.
3. Together with the global experiments backward extension, the regional ICON-CLM simulations have also been extended to the same period in both EUR011 and GER00275 domains for ensemble member

1 (3a). For the most recent period (January 2017-September 2022), the number of ensemble members in the EUR011 domain has been extended from one to five (3b). With the downscaling of all ensemble members, we added robustness to the results obtained over the previous report period, published in Klimiuk et al. (2024), and began the analyses of soil moisture-temperature coupling, its response to global warming and its contribution to the magnitude of 2m temperature response (publication in preparation). The backward extension will be a critical contribution to a project synthesis paper in preparation.

4. In addition, we tested a new hybrid approach that combines the standard PGW and the global nudged storyline scenarios performed with the AWI-CM1 to simulate how the Ahr Flood event in July 2021 would unfold under different future climate conditions with ICON-CLM. The idea is to utilise a hybrid approach that uses climate change signals from the global nudged AWI-CM1 simulations for the 2K, 3K, and 4K warmer world to perturb the ERA5 data that would finally lead to a realistic representation of the Ahr flood event. Prior to the future climate simulations, it was necessary to determine the optimal initialization time of the ICON-CLM model in order to accurately reproduce the magnitude and location of the event based on ERA5 boundary conditions. For this purpose, the ICON-CLM model was run at 6-hour intervals from 5 days before the onset of the event until the onset of the event itself over Europe at 12-km grid spacing and over Germany at a 3-km convection-permitting scale. With the best performing initialization times (i.e., 13/07/2021-18:00, 14/07/2021-00:00, 14/07/2021-06:00), which simulates July 2021 heavy precipitation event in ±5 mm precision, the hybrid approach was utilised to simulate future projections under the 2K, 3K, and 4K warmer world conditions. The perturbations were done in three different ways described in 3a, 3b and 3c.

Not only are these simulations being used internally, but several project partners have also utilised the simulations for their studies, with multiple papers either accepted, submitted or in preparation for submission. These studies cover a range of topics, from analysing the vulnerability of European agricultural areas (Martin et al. submitted) to studying droughts using hydrological models (Rakovec et al. in prep), and mortality in the context of global warming (Schachtschneider et al., 2024). Additionally, external researchers have leveraged the simulations to study record-breaking cold extremes in East Asia (Zhuo et al., 2024) or validation of CMIP6 models in the Arctic (Trivedi et al., 2024).

This wide range of applications and collaborations has required extensive post-processing and data storage, which was made possible through the resources granted in this project. While the extensive post-processing, data storage requirements and project deliverables initially led to expired resources in the first quarter, all granted node hours were used in the subsequent quarters, and this trend is expected to continue in the future.
Due to the cut in HLRE-4 node hours, some of the planned simulations, like the "new long nudged runs", which consist of several shorter (5-year) overlapping nudged runs, with the dynamical conditions progressively shifted by one year have not been able to be completed.

References:

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