Project: **1264**
Project title: **Storyline simulations of extreme events with spectral nudging**
Principal investigator: **Helge Gößling**
Report period: **2021-11-01 to 2022-10-31**

This report shows the completed and ongoing work employing the computational resources allocated in the ba1264 project. As described in the proposal, the goal of this computing project has been to explore the storyline approach at an unprecedented level of detail. We have produced a broad set of experiments using two different coupled climate models (AWI-CM1 and AWI-CM3, see more information in the proposal) in which the atmospheric circulation has been nudged to the observed one (trying different nudging configurations).
Almost all the HLRE-4 node hours granted in the first two quarters (and to some extent in the third one) expired as the model components and the ESM-Tools (needed to run our models) had to be ported to and optimised for the new machine. These processes were completed and some benchmarking was performed by September, and we now have both models running on Levante (with only some minor issues related to SLURM, open ticket #118631).
The following simulations have been produced until today using the granted resources:

1. "Short nudged runs" (2017-2021 dynamical conditions) using a wide set of nudging parameters with AWI-CM3 (more details in the proposal). After performance tests, we produced "storyline runs" (5 ensemble members from 1st January 2017 to 31st December 2021 dynamical conditions in different global warming scenarios with both climate models) using the following nudging parameters: T20 wavenumber truncation and 24 h relaxation time ("soft nudging", same as in Sánchez-Benítez et al., 2022), and T127/T159 wavenumber truncation for AWI-CM1/AWI-CM3 and 1 h relaxation time ("strong nudging").
2. "Long nudged runs" (1979-2021 dynamical conditions constrained, as the extension of ERA5 back to 1950 is not yet in the final version) with both climate models. One “long nudged run” with “soft nudging” has been performed with AWI-CM1 in pre-industrial and present conditions, and two “long nudged runs” with both “soft” and “strong nudging” have been performed with AWI-CM3 in present climate.
3. An extension of the AWI-CM3 “free run” has been performed over 2015-2099, using the SSP370 forcing.

As main results, we can summarise the following:

The extension of the previous "storyline runs" allows us to study how various outstanding extreme events experienced in the last years (e.g., summer 2019 North Pacific marine heatwave, Western North America or Siberian heat waves, Western Europe floods) would unfold in different past and plausible future climates. For most of them, the simulations using "soft nudging" from both models reproduce the observed event. For the Western Europe floods, the precipitation pattern was well reproduced, but we failed to capture the event's peak, likely due to local influences. This issue was corrected (in a similar way in both models) using the "strong nudging" configuration, as seen in Figure 1. Similar conclusions were obtained by Pithan et al. (2022), emphasising the importance of choosing the nudging parameters depending on the spatio-temporal scale of the event. Using the appropriate nudging configuration, we are currently exploring how these extreme events would have unfolded in a preindustrial climate or how they would evolve in plausible future climates (papers in preparation).

"Long nudged runs" allow us to analyse how the observed variability (including, but not limited to, a broad range of similar extreme events) is replicated in our climate models. Flow-dependent biases or differential climate change influence is being analysed (paper in preparation). The selection of a longer period is also better suited to properly spin up all aspects of the more slowly varying components, such as soil hydrology and subsurface ocean temperatures, so that they are brought into the correct phase of internal variability. Another critical point is how strongly the nudging influences the overall model climate. This impact is complicated to see in the "short nudged runs". In the "long nudged runs", a climate drift has been observed (Figure 2), which is currently being analysed in more detail. Therefore these “long nudged runs” are useful to compute anomalies based on these (instead of the free run), which may make a non-negligible difference.

To perform storylines in future climates using the prototype AWI-CM3 model, we initially extended the existing historical run used for model evaluation in Streffing et al., 2022. The transient climate response of the model was used to determine the forcing year of scenario SSP370 corresponding to a +4K world. However, the analysis of this free run revealed the absence of transient aerosol forcing in AWI-CM3 (i.e., in its atmospheric component OpenIFS-43r3). The pending implementation of transient aerosols in AWI-CM3 therefore prevented further

(meaningful) free-running or nudged simulations with scenario forcing(s). This, together with the delay due to the system migration and the reduced resource allocation, is the reason why we have not been able to conduct the planned higher-resolution simulations.

Beyond our analyses, the data obtained in these simulations have been post-processed and are currently available for all the SCENIC project partners. These data are being used for dynamical downscaling, AI algorithms, and impact modelling. Furthermore, both AWI-CM1 and AWI-CM3 “short-nudged runs” in the present-day climate have been used to carry out meaningful comparisons to MOSAiC observations in the Arctic (see Pithan et al., preprint).
By the end of q4, "long nudged runs" with AWI-CM1 will be extended to +2K, +3K and +4K climate forcings. These simulations will continue to be limited to only one ensemble member due to the reduction of the granted resources. As soon as the 2021-2022 ERA5 data is made available on the Levante data pool, all the "short nudged simulations" for both AWI-CM1 and AWI-CM3 will be extended until the end of 2022. This will use the storage and HLRE-4 node hours allocated this quarter.

References:

Pithan, F., et al.: Nudging allows direct evaluation of coupled climate models with in-situ observations: A case study from the MOSAiC expedition, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2022-706, 2022

Streffing, J., et al.: AWI-CM3 coupled climate model: description and evaluation experiments for a prototype post-CMIP6 model, Geosci. Model Dev., 15, 6399–6427, https://doi.org/10.5194/gmd-15-6399-2022, 2022.

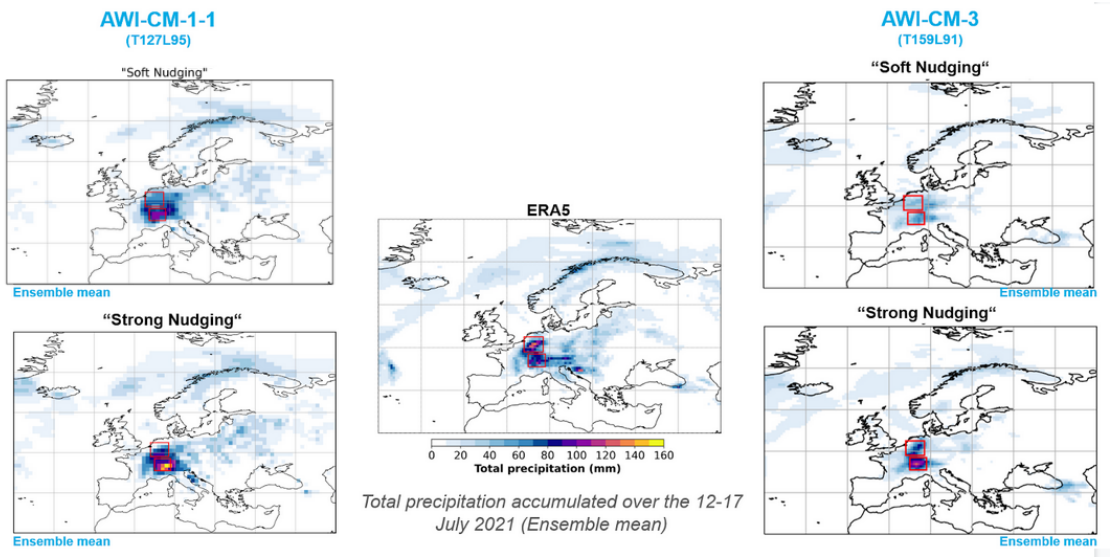

Figure 1. Total precipitation accumulated over 12-17 July 2021 (ensemble mean) using (left) AWI-CM1 and (right) AWI-CM3 with (top) “soft nudging” and (bottom) “strong nudging”. Same field from ERA5 included in the middle for comparative purposes.

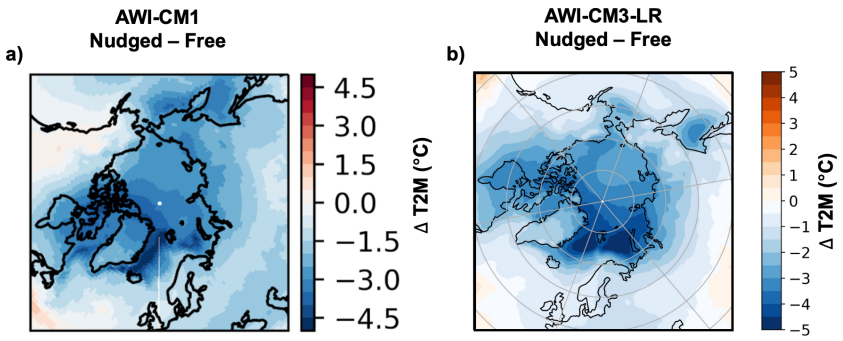

Figure 2. Differences in 2-m air temperature climatology (1979-2020) between the “soft nudging” long runs and the free-running simulations, for AWI-CM1 and AWI-CM3-LR.