Project: **1103**

Project title: **AWI-CM with carbon cycle**

Principal investigator: **Judith Hauck**

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

Maximum of 2 pages including figures. 9 pt minimum font size.

As requested for this report period, coupled climate model simulations were conducted on DKRZ Levante with AWI-ESM-1-REcoM, the Alfred Wegener Institute Earth System Model version 1. AWI-ESM-1-REcoM is based on the same setup that was utilized for CMIP6 DECK simulations, as described in Semmler et al., (2020). In addition, the Regulated Ecosystem Model version 2 (REcoM2) simulates the ocean biogeochemistry in this coupled setup (Hauck et al., 2013, Schourup-Kristensen et al., 2014). Output from concentration-driven historical and scenario CMIP6 experiments (Coupled Model Intercomparison Project 6, Eyring et al., 2016) previously simulated on Mistral/Levante with AWI-ESM-1-REcoM (see report 2022) is currently included in a multi-model comparison study that investigates the temporal variability of the oceanic carbon sink and identifies so far undocumented ESM deficiencies (Danek and Hauck, 2023, in preparation). CMORization of this coupled model output was started in 2023 and is currently ongoing, whereby Echam/Jsbach output is going to be CMORized by DKRZ staff, while FESOM/REcoM output by AWI staff.

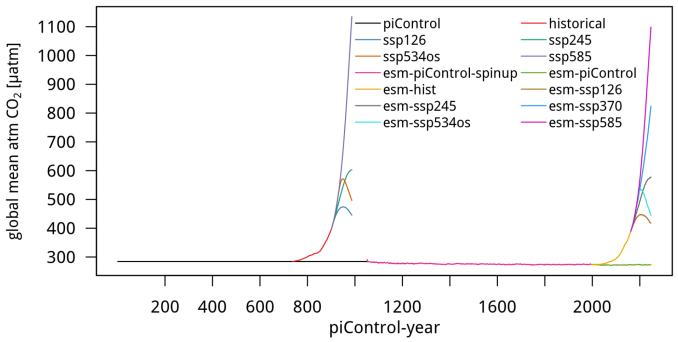

Fig. 1: Global and annual average atmospheric CO2 concentration modeled with AWI-ESM-1-REcoM in concentration- (up to model year ~900) and emission-driven CMIP6 experiments.

In 2023, emission-driven CMIP6 simulations were conducted as planned for a set of scenarios (Fig. 1). As planned, the quasi-equilibrium esm-piControl experiment was utilized as the initial condition for OceanNET and RETAKE simulations. Seifert et al., (2023, in preparation) were able to conduct ocean alkalinity enhancement (OAE) experiments, in which the effect of an artificial ocean alkalinity increase is investigated in coastal regions of the northern hemisphere (Fig. 2). Almost all planned OceanNET simulations were conducted, with the remainder currently running on Levante and estimated to be completed by the end of 2023. Similarly, AWI-ESM simulations are currently running for RETAKE in order to compare OAE efficiency globally and in deep water formation regions. Here, the ESM simulations conducted on Levante will be used to assess Earth System feedbacks in comparison to a similar set of simulations conducted in ocean-only mode (Nagwekar et al., 2023, submitted).

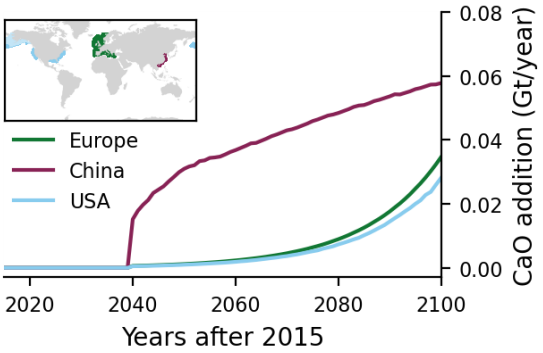

Fig. 2: Areas and concentrations of lime (CaO) addition between 2040 and 2100 in the ocean alkalinization experiments with AWI-ESM-1-REcoM.

Later in 2023, AWI-ESM-1-REcoM was added to the model intercomparison project SOFIA, focussing on Antarctic meltwater effects on the global climate as simulated in ESMs (Southern Ocean Freshwater release model experiments InitiAtive; Swart et al., 2023, accepted; see additional request 2023). For this, terrestrial runoff resulting from climate change is distributed over wet ocean model nodes along the Antarctic coast, also known as hosing. The Tier-1 experiment 'antwater' was simulated with AWI-ESM-1-REcoM (Fig. 3) and will be used to obtain a model uncertainty estimate in ESM hosing experiments within SOFIA. Hosing experiments over the historical period are currently running.

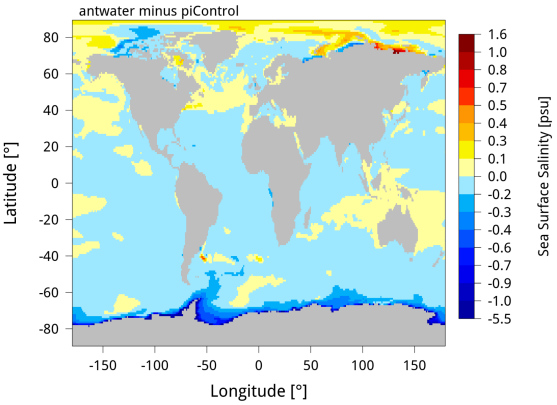

Fig. 3: 100-year mean of sea surface salinity anomaly antwater minus piControl, i.e. the effect of 0.1 Sv freshwater input along Antarctica modeled with AWI-ESM-1-REcoM.

In addition, we report on simulations conducted under ab1095 as this will be important for the current request. Here, the quasi-equilibrium esm-piControl state was utilized for a 'dead ocean' experiment in which the effect of the biological ocean carbon pump will be investigated by setting the photosynthesis activity to zero. As previous estimates on the effect of atmospheric carbon drawdown by oceanic phytoplankton are both sparse and possibly outdated (e.g. Maier-Reimer et al., 1996), our experiment provides a valuable estimate on the effect of the biological carbon pump on atmospheric CO_2 with a fully coupled ESM. After ~1100 model years, the atmospheric CO_2 increased by ~109 µatm (Fig. 4), which represents a much smaller and slower effect as documented in earlier studies (Maier-Reimer et al., 1996).

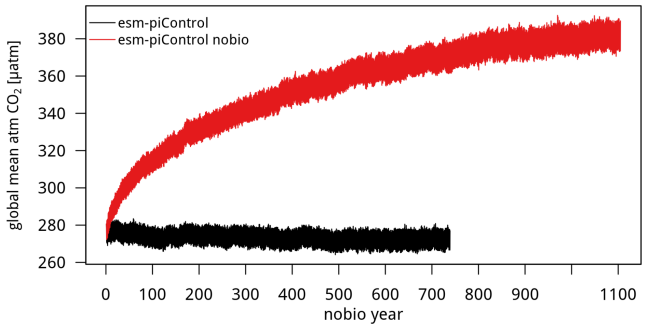

Fig. 4: Global mean monthly atmospheric CO_2 partial pressure in esm-piControl (black) and dead ocean (red) experiments modeled with AWI-ESM-1-REcoM. The last-100-year averages and linear temporal trends are 274.2 and 383.4 µatm, and 0.5 µatm (century)$^{-1}$ and 2.34 µatm (century)$^{-1}$, respectively. The dead ocean yields an atmospheric CO_2 increase of ~109 µatm after ~1100 years.

AWI-ESM-1-REcoM output was/is further utilized in the collaboration projects Santana-Falcón and Séférian (2022), Mongwe et al., (2023, in revision), Heinze et al. (2023, in review) and Oziel et al., (2023, in preparation). Data transfer to the tape archive is currently ongoing.

References

- Danek and Hauck, 2023 (to be submitted to Climate Dynamics): Discrepancies in temporal pCO_2 variability estimates from Earth System Models and pCO_2-products related to high-latitude mixed layer dynamics.
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- Maier-Reimer et al., 1996: https://link.springer.com/article/10.1007/s003820050138
- Mongwe et al., 2023 (in revision at Nat. Comm.): Poleward migration of the dominant CO_2 sink region in the Southern Ocean under high emission-scenario.
- Nagwekar et al., 2023 (submitted to Earth's Future): Effects of Ocean Alkalinity Enhancement in the deep and bottom water formation regions on the 21st century CO_2 uptake under low and high emission pathways.
- Oziel et al., 2023 (in preparation): Climate change and terrigenous inputs decrease the efficiency of the future Arctic Ocean's Biological Carbon Pump
- Santana-Falcón and Séférian, 2022: https://www.nature.com/articles/s41558-022-01476-5
- Schourup-Kristensen et al., 2014: https://gmd.copernicus.org/articles/7/2769/2014/
- Seifert et al., 2024 (in prep): Ocean alkalinity enhancement with direct carbonate system effects on biology in AWI-ESM
- Semmler et al., 2020: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019MS002009
- Swart et al., 2023 (accepted): https://egusphere.copernicus.org/preprints/2023/egusphere-2023-198/