Project: 1103
Project title: AWI-CM with carbon cycle
Principal Investigator: Judith Hauck (AWI)
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Progress in 2021

This project is about an interactive carbon cycle with CO_2 exchange between ocean and atmosphere. For this aim, we coupled the ocean biogeochemistry and ecosystem model REcoM2, developed at AWI, to the AWI Climate Model AWI-CM to allow for an interactive carbon cycle with CO_2 exchange between ocean and atmosphere, within the framework of the Helmholtz Young Investigator Group 'Marine carbon and ecosystem feedbacks in the Earth System' (MarESys).

The group has grown in 2021, so that we have more personal power behind these coupled simulations since June 2021. In the first half of 2021, we had technical problems with the updated python-based version of esm_tools (https://github.com/esm-tools/esm_tools), which prevented us from starting the readily prepared historical simulation and emission-driven spin-up in the first quarter of 2021. This led unfortunately to an expiration of computing resources. The technical difficulties are solved by now, and the model runs smoothly in multiple setups.

We have by now a 736 year concentration-driven spin-up simulation (from ba1103 and ab1095 resources), which we have evaluated and found to be reasonable in atmospheric temperature, ocean and ice physical parameters (e.g. ocean temperature and salinity, ice area and thickness, transport: Drake Passage transport ca. 130 Sv), and ocean biogeochemistry (primary production (ca. 30 PgC/yr), carbon and nutrient distributions) as described in the previous report.

From this concentration-driven spin-up we branched off historical and piControl simulations. The piControl extension (1850-2100) is expected to finish within 1-2 weeks. The historical simulation (1850-2014) ran until 1980; however, a first inspection revealed a suspicious land carbon flux, which we could attribute to an erroneous path for the land use change transition in the esm_tools. We currently discuss options to repeat the full historical simulation on AWI resources.

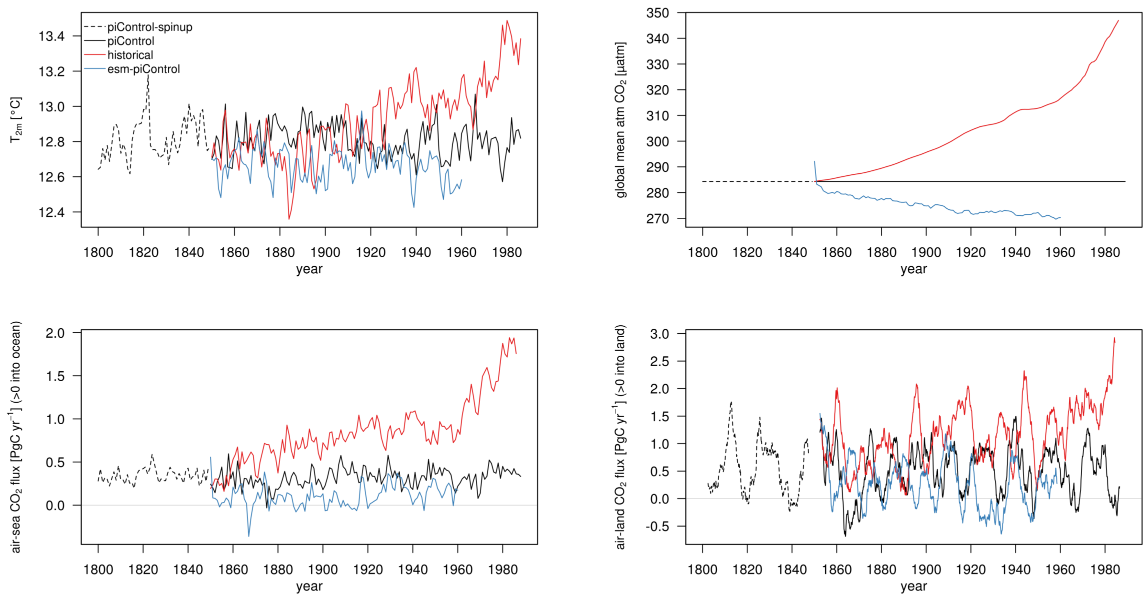

Figure 1: AWI-CM1-REcoM2 piControl (black), historical (red) and esm-piControl (blue) annual global mean 2m air temperature (top left) and atmospheric CO_2 concentration (top right) as well as globally integrated air-sea (bottom left) and air-land (bottom right) CO_2 fluxes. The latter is shown as a 5-year running mean to highlight the differences between the experiments.

Figure 1 illustrates atmospheric temperature, partial pressure of atmospheric CO_2, air-sea and air-land CO_2 fluxes from the concentration-driven piControl and historical simulations as well as from the emission-driven spin-up. In the concentration-driven historical simulation, the magnitude of global mean temperature evolution is consistent with the results of simulations performed by other groups at AWI (without carbon cycle, Semmler et al., 2020) and atmospheric CO_2 partial pressure and the ocean carbon sink follows the expected increase (e.g. Friedlingstein et al., 2020), with increased carbon uptake in the Atlantic and Pacific subpolar gyres (Figure 2). The land sink increases over the historical simulation as expected (e.g. Friedlingstein et al., 2020), e.g., with contribution from boreal forests (Figure 2). However, as indicated above, the land sink is overestimated by not accounting for the land use change transition.

The emission-driven spin-up simulation ran for roughly 110 years. Over this period, the land sink has varied around zero (mean +0.27 PgC/yr) with a small trend towards outgassing (-0.55 PgC/yr/century). The ocean sink (mean +0.11 PgC/yr; trend towards more uptake of +0.1 PgC/yr/century) has a smaller bias than in the concentration-driven piControl (which itself, with an ocean uptake of +0.34 PgC/yr, was in the same range as other Earth System Models (e.g. CNRM -0.9 PgC/yr, IPSL +0.35 PgC/yr). Together this leads to a modest drop in atmospheric CO_2 concentration and reaches 270 µatm after 110 years. We will continue to investigate whether an equilibrium at the envisaged 284 µatm can be reached with a sufficiently long simulation time by monitoring atmospheric CO_2, but also by analyzing ocean and land carbon fluxes and stocks. This might lead to additional sensitivity simulations to reach a constant atm. CO_2 of around 284 µatm in emission-driven mode.

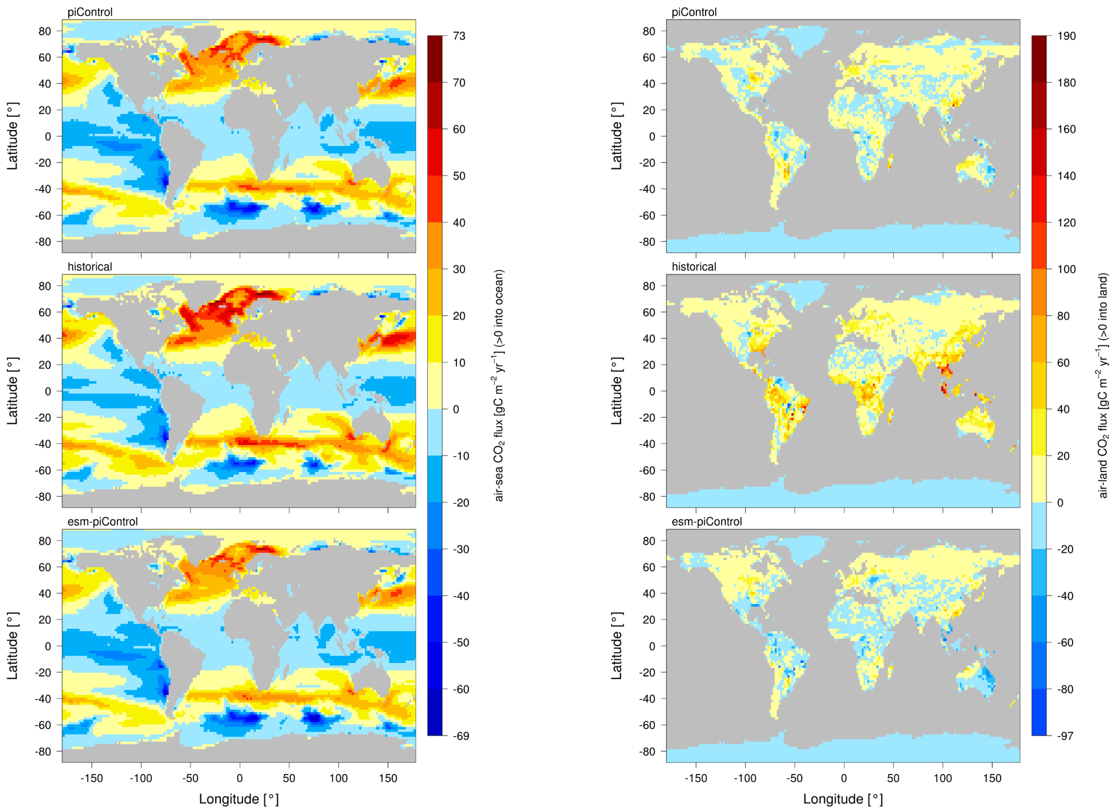

Figure 2: AWI-CM1-REcoM2 piControl (top), historical (middle, 1967-1986) and esm-piControl (bottom) 20-year annual mean air-sea (left) and air-land (right) CO_2 fluxes.

Given the 40% cut in node hours relative to the requested resources, plus the technical difficulties in the first half of 2021 and accompanying expiration of resources, we could not run the idealized 1 % per year CO_2 simulation (concentration-driven '1pctCO2') for 1850-2000 (151 years), and will not be able to run a future simulation (ssp585) with the remaining resources in this allocation period.

References:

Friedlingstein et al. (2020), doi:10.5194/essd-12-3269-2020;
Semmler et al. (2020), https://doi.org/10.1029/2019MS002009