Earth system modelling with high resolution ocean nests

Are simulated marine biogeochemical-climate interactions better at high resolution?

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In Short

- Simulations with a nested configuration of the Earth system model FOCI with marine biogeochemistry are envisioned.
- Experiments will enable a comparison between nested and un-nested configurations to determine how model resolution affects simulated biogeochemical-climate interactions, including during a scenario with CO_2 removal (negative emissions).
- A total of 1301 kNPL and 72.3 TB are being requested for the period 01.01- 31.12.2021

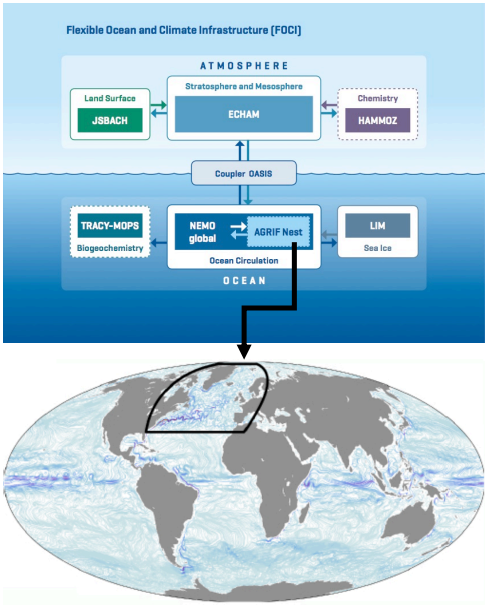

***Figure 1:** FOCI model components and AGRIF nest location.*

Anthropogenic-driven climate change is increasing the likelihood of "severe, pervasive, and irreversible" impacts upon society and natural systems [1]. Societies have recognized that these impacts need to be quantified and that anthropogenic CO_2 emissions must be rapidly reduced to avoid potentially catastrophic impacts. In addition to reducing CO_2 emissions to near zero, it is also likely that CO_2 removal (CDR) will be needed to limit or even reverse climate change. However, the climatic and biogeochemical implications of mitigation activities that include CDR are not fully understood [2].

Earth system models (ESMs) are one of the key tools that can be used to help understand the implications of climate change and proposed mitigation activities. One state-of-the-art ESM is the Flexible Ocean and Climate Infrastructure (FOCI; Figure 1) model, which has been successfully developed at GEOMAR (projects shk00018 and shk00043) as part of the Helmholtz Advanced Earth System Modelling Capacity initiative. This model consists of a fully coupled atmosphere-ocean-sea-ice general circulation model, a land model, and a marine biogeochemistry model component that enables the simulation of marine biological processes, the marine carbonate system, and air-sea gas exchange. While the standard FOCI configuration shows great potential for simulating the Earth system [3,4], within FOCI there is also an option for regional horizontal grid refinement in the ocean, from the standard 1/2° to 1/10° (so called "nesting", shk00028 + shk00029).

The option to use nested grids in the ocean, allows for mesoscale physical features such as ocean eddies to be explicitly resolved in targeted regions, potentially leading to more realistic simulations and localized quantification of climatic and biogeochemical dynamics. However, the FOCI nesting option has not yet been used with the marine biogeochemistry component and it is unknown if such a configuration will improve the simulated climate and biogeochemical cycling. It is also not clear how the ocean will respond in such a configuration when CO_2 removal is simulated as a climate change mitigation approach.

In this current proposal, we seek computing resources for 2021 to produce a first set of simulations with the nesting option and marine biogeochemisty. The major objectives of the project are to determine if nesting improves (1) FOCI's simulated carbon cycle and climate-carbon cycle interactions; (2) simulated preindustrial and historical marine biogeochemical tracer distributions (e.g. nutrients and oxygen); and (3) the response of the climate in an overshoot scenario with CDR. The nested and non-nested FOCI simulations will also be compared with results from model intercomparison projects (CMIP6 and CDR-MIP) [2,5].

For several simulations we will follow the experimental protocols outlined in HLRN-FOCI project shk00043 (+ a submitted continuation proposal) with the only difference being in the nested configuration of the model. We also propose to run a future climate change scenario, which includes large amounts of CO_2 removal (net negative emissions). The proposed simulations are:

1. Spin-up: All forcing constant at year 1850 level for as long as possible (until surface is in equilibrium); CO_2 concentration prescribed
2. *esm-piControl*: A continuation of the spin-up with the main difference being that atmospheric CO_2 is allowed to freely evolve; serves as a pre-industrial control run
3. *esm-hist*: Historical simulation from 1850-2014; branches off of *esm-piControl*; historical forcing with CO_2 determined by emissions
4. *esm-ssp534-over*: CO_2 emission-driven SSP5-3.4 overshoot climate change scenario [6] simulation from the 2014 to 2100

In the longer term (2022-2024), we will carry out experiments for the EU Horizon 2020 project OceanNETs (https://www.oceannets.eu/) to determine if model resolution matters when simulating different types of ocean-based CDR. The simulations proposed here and completed in shk00043 (+ submitted continuation proposal) will be used as control simulations for the OceanNETs experiments.

WWW

https://www.esm-project.net

More Information

[1] IPCC, *5th Report of the Intergovernmental Panel on Climate Change*. WG I (2013).

[2] Keller et al., *Geosci. Mod. Dev.* 11(3), 1133-1160 (2018). https://doi.org/10.5194/gmd-11-1133-2018

[3] Matthes et al., *Geosci. Mod. Dev.* 13(6), 2533-2568 (2020). https://doi.org/10.5194/gmd-13-2533-2020

[4] Chien et al., *Geosci. Mod. Dev.* (in prep)

[5] Eyring et al., *Geosci. Mod. Dev.* 9(5), 1937-1958 (2016). https://doi.org/10.5194/gmd-9-1937-2016

[6] Riahi et al., *Glob. Env. Chg.* 42, 153-168 (2017). https://doi.org/10.1016/j.gloenvcha.2016.05.009

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