Earth system modelling with high resolution ocean nests

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

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In Short

- Initial simulations with a nested configuration of the Earth system model FOCI with marine biogeochemistry show improved distributions of biogeochemical tracers.
- Further simulations will enable a comparison between nested and un-nested configurations to determine how model resolution affects simulated biogeochemical-climate interactions over the historical period and in future scenarios, including during a scenario with CO_2 removal (negative emissions).
- A total of 976 kNPL and 72.1 TB are being requested for the period 01.01- 01.10.2022

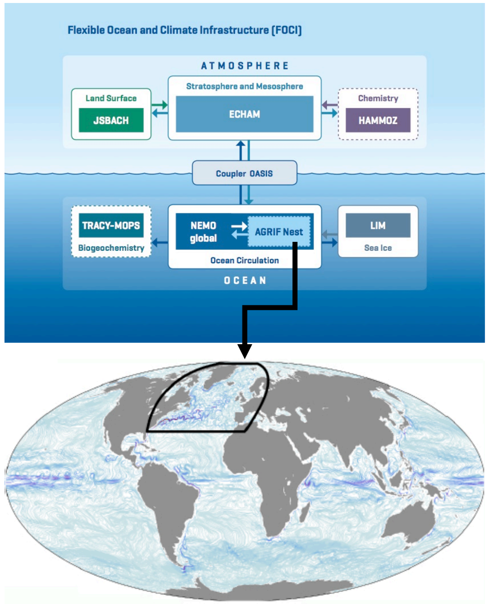

***Figure 1:** FOCI model components and AGRIF nest location.*

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 only begun to be run with the marine biogeochemistry component and it is unknown if such a configuration will improve the simulated climate and biogeochemical cycling; although early results are promising (Figure 2). 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.

Here we seek to extend previously allocated computing resources into 2022 to complete a set of FOCI 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 CDRMIP) [2,5].

For several simulations we will follow the experimental protocols outlined in HLRN-FOCI project shk00043 with the only difference being in the nested

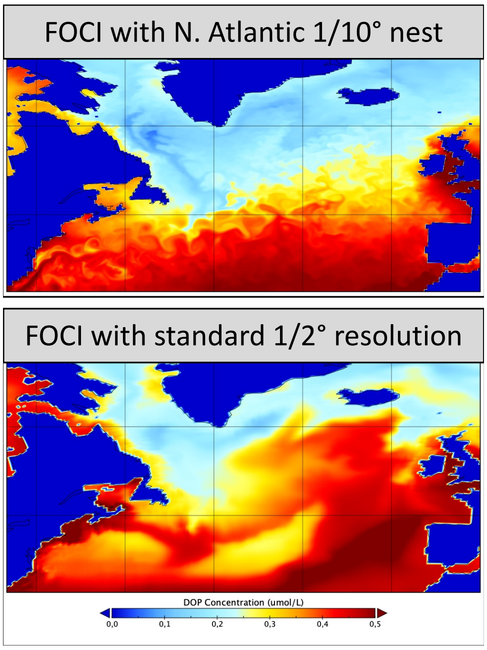

***Figure 2:** Comparison of surface dissolved organic phosphorus (DOP) distribution with and without the nest in FOCI.*

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 spin-up simulation has been completed with the initial project resources. The proposed simulations are:

1. *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

2. *esm-hist*: Historical simulation from 1850-2014; branches off of *esm-piControl*; historical forcing with CO_2 determined by emissions

3. *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 in shk00045 and those completed in shk00043 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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