# Integration of marine biogeochemistry into a dynamic atmosphere-land-ocean model

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## In short

- The new general circulation climate model, FOCI (Flexible Ocean and Climate Infrastructure), has been successfully developed (shk00018, shk00028, shk00029) as part of the Helmholtz initiative Advanced Earth System Modelling Capacity and is now expanded by the implementation of the marine biogeochemistry model TRACY-MOPS (TRAcer Calibrated cYcles | Model of Oceanic Pelagic Stoichiometry)[1–4].

- The addition of the biogeochemistry together with the pre-existing land model turns FOCI into a full general circulation earth system model (ESM). Therefore, FOCI closes a gap at GEOMAR in terms of models available and allows a multitude of new research opportunities, and it will also benefit partners within the Advanced Earth System Modelling Capacity initiative at the Helmholtz association.

- The option of high resolution regions in the ocean enables, for example, the investigation of the effects of eddies on ocean heat and carbon uptake and thus on global mean surface warming and global carbon budgets. This will be scientifically relevant not only under climate change conditions, but also under the implementation of geoengineering techniques which artificially increase ocean carbon uptake.

- In order to undertake these and other investigations the performance of the biogeochemical model and the climate-carbon cycle performance of FOCI need to be accessed, which is the aim of the research proposal presented here.

Climate change induced by anthropogenic forcings, mainly anthropogenic $CO_2$ emissions is one of the great challenges to human societies. The implementation of a global carbon cycle into climate models [5,6] revealed for example significant positive climate-carbon cycle feedbacks or that global mean warming is approximately proportional to cumulative $CO_2$ emissions [7].

A multitude of important research has been performed at GEOMAR using an ESM (University of Victoria Earth System Climate Model, UVic ESCM [8]), for example in the fields of geoengineering [9–11] or oxygen minimum zones [12]. Also, the question of how much global mean surface air warming would need to be expected from a certain amount of cumulative $CO_2$ emissions has been investigated with UVic ESCM [13].

However, UVic ESCM is only an ESM of intermediate complexity as the atmosphere is not described with a general circulation model but a simple one-dimensional energy balance model and the ocean model has a relatively coarse resolution.

Here, the successfully developed coupled atmosphere-ocean general circulation model FOCI (part of shk00018) is being extended by the marine biogeochemistry model TRACY-MOPS[1–4]. Due to an already existing land surface scheme (JSBACH[14]), this extension enables the simulations of the full carbon cycle and thus turns FOCI into a full ESM. The use of FOCI extends the research options relative to what is possible using UVic ESCM, as atmosphere-ocean interactions can be studied due to the atmosphere general circulation model in FOCI (ECHAM, European Center HAMburg[15]). Furthermore, the ocean model in FOCI (NEMO, Nucleus for European Modelling of the Ocean[16]) has a much higher resolution compared to the one in UVic ESCM (1/2° relative to 1.8°x3.6°horizontal resolution and 46 relative to 19 vertical layers). Especially, the option for ocean regional grid refinement (1/10° horizontal resolution, shk00028 + shk000029) opens pathways for more detailed research as it allows to study the effect of eddies in the ocean. For example, the effect of resolving eddies, instead of using parametrizations for eddies, on ocean heat and carbon uptake and thus on the relationship between global mean surface temperature change and cumulative $CO_2$ emissions can be studied. This can be done under climate change scenarios but also under scenarios that include the implementation of techniques that artificially increase ocean carbon.

Prior to pursuing any of these promising research opportunities the newly implemented biogeochemistry model as part of a general circulation model and the performance of FOCI as an ESM (e.g., carbon budgets, climate-carbon cycle interactions) need to be assessed. This assessment will be done by comparison with simulations from model intercomparison studies and observational data. Therefore, the planned simulations follow the protocol of the Coupled Model Intercomparison Project Phase 6 (CMIP6) for the DECK (Diagnostic, Evaluation and Characterization of Klima) and the CMIP historical simulations (1850 – near present) [17]. The DECK simulations are a spin-up simulation, two preindustrial control simulations (either prescribing $CO_2$ concentration or emissions from year 1850) and a simulation with one percent yearly increasing atmospheric $CO_2$ centration for 150 years, while keeping all other forcing agents constant at year 1850 levels. There are also two CMIP historical simulations, again once prescribing atmospheric $CO_2$ concentration and once prescribing $CO_2$ emissions. All forcing agents vary according to historical data (provided by the CMIP community) in the historical simulations.

## References


1. Kriest, I. & Oschlies, A. MOPS-1.0: Towards a model for the regulation of the global oceanic nitrogen budget by marine biogeochemical processes. *Geosci. Model Dev.* **8,** 2929–2957 (2015).
2. Kriest, I. Calibration of a simple and a complex model of global marine biogeochemistry. *Biogeosciences* **14,** 4965–4984 (2017).
3. Kriest, I. *et al.* Calibrating a global three-dimensional biogeochemical ocean model (MOPS-1.0). *Geosci. Model Dev.* **10,** 127–154 (2017).
4. Orr, J. C. & Epitalon, J. M. Improved routines to model the ocean carbonate system: Mocsy 2.0. *Geosci. Model Dev.* **8,** 485–499 (2015).
5. Sarmiento, J. L. *et al.* Simulated response of theoceancarboncycle to anthropogenic climatewarming. *Nature* **393,** 1–2 (1998).
6. Cox, P. M. *et al.* Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. *Nature* **408,** 184–7 (2000).
7. Matthews, H. D. *et al.* The proportionality of global warming to cumulative carbon emissions. *Nature* **459,** 829–32 (2009).
8. Weaver, A. J. *et al.* The UVic earth system climate model: Model description, climatology, and applications to past, present and future climates. *Atmosphere-Ocean* **39,** 361–428 (2001).
9. Keller, D. P. *et al.* Potential climate engineering effectiveness and side effects during a high carbon dioxide-emission scenario. *Nat. Commun.* **5,** 1–11 (2014).
10. Feng, E. Y. *et al.* Model-Based Assessment of the CO 2 Sequestration Potential of Coastal Ocean Alkalinization Earth ' s Future. *Earth's Futur.* **5,** 1252–1266 (2017).
11. Reith, F. *et al.* Revisiting ocean carbon sequestration by direct injection: a global carbon budget perspective. *Earth Syst. Dyn.* **7,** 797–812 (2016).
12. Niemeyer, D. *et al.* A model study of warming-induced phosphorus–oxygen feedbacks in open-ocean oxygen minimum zones on millennial timescales. *Earth Syst. Dyn.* **8,** 357–367 (2017).
13. Ehlert, D. *et al.* The Sensitivity of the Proportionality between Temperature Change and Cumulative CO 2 Emissions to Ocean Mixing. *J. Clim.* **30,** 2921–2935 (2017).
14. Schneck, R. *et al.* Land contribution to natural CO2 variability on time scales of centuries. *J. Adv. Model. Earth Syst.* **5,** 354–365 (2013).
15. Stevens, B. *et al.* Atmospheric component of the MPI-M Earth System Model: ECHAM6. *J. Adv. Model. Earth Syst.* **5,** 146–172 (2013).
16. Madec, G. *NEMO Ocean Engine*. (Note du Pˆ ole de mod´ elisation de l'Institut Pierre-Simon Laplace (IPSL), France, No 27, ISSN No 1288-1619, 2016).
17. Eyring, V. *et al.* Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. *Geosci. Model Dev.* **9,** 1937–1958 (2016).