Iron control of marine biogeochemical cycles

Iron control of marine biogeochemical cycles of phosphorus, nitrogen and oxygen

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In Short

- Iron is considered one of the essential elements controlling marine primary production and carbon transfer into the deep ocean
- A recent model intercalibration project (MIP) showed that global marine biogeochemical models including a prognostic iron model show large differences in their skill to reproduce observed patterns of dissolved iron in the ocean
- We use a recently developed computational method to calibrate essential, in particular iron cycle related, parameters of global biogeochemical models
- From a systematic comparison of calibrated models with and without prognostic iron module, we attempt to answer the question to what extent a dynamic iron cycle is an essential component of biogeochemical models in an Earth system and climate context

Motivation The biological pump, transferring carbon from the sea-surface to the deep ocean, plays a central role in the marine carbon cycle in modulating the Earth's climate. The trace element iron (Fe) is considered one of the essential elements controlling primary production in the surface ocean and the efficiency of the transfer of carbon from the surface to the deep ocean [1,2]. Consequently, many marine biogeochemical models used in climate research include the marine Fe cycle. So far, however, these modules have only been qualitatively tuned against observations, for example of dissolved free iron. A recent model intercomparison, comparing 13 global ocean biogeochemistry models against the latest oceanic sections from the GEOTRACES program, showed that all models showed clear deficits in reproducing many aspects of the observed patterns [3].

Despite the importance for the global carbon cycle and related climate, efforts into objective calibration of model parameters of iron-related processes have been quite limited. This is due to (a) the complexity of the marine iron cycle, (b), the time scales involved in whole ocean biogeochemical cycles of several thousand years requiring long model integration times, (c) the lack of sufficient global iron data, and (d) the lack of a suitable parameter calibration technique until recently.

Offline representations of ocean circulation, like the Transport Matrix Method (TMM, [4]) are fast enough to be combined with methods of parameter optimization. Recently, Kriest and co-workers [5] have used the TMM in the framework of a Covariance Matrix Adaption Evolution Strategy (CMA-ES, [6]) and demonstrated that a pre-selected subset of parameters of a global ocean biogeochemical model can be calibrated against available oceanic observations of macronutrients and oxygen. In their study, the pre-selection process of parameters was guided by avoiding obviously related model parameters (like, e.g., the sinking speed of organic matter and the remineralization rate constant of organic matter) and by earlier sensitivity experiments carried out for the same model.

Objectives Here we adopt that approach and propose a systematic comparison of the skill of models with and without an iron module by means of a parameter calibration approach. In a series of three independent parameter calibration experiments, we will in particularly explore whether the inclusion of Fe-related processes improves the model skill to reproduce the observed global patterns of macronutrients and oxygen, the prime tracers of the biological pump, for which a rich observational data base exists. Thereby we attempt to answer the question whether iron is an essential component of biogeochemical models in an Earth system and climate context.

Own previous work Recently a prognostic model of the marine iron cycle [7] has been implemented into the UVic Earth System Climate Model of intermediate complexit [8]. So far the online version of Uvic with a prognostic iron cycle has been subjectively tuned against observations of dissolved free iron and other marine data [7]. Recently, the marine component of the Kiel Uvic version has been ported into the Transport Matrix Method (TMM) framework [4,9,10], which provides a parallelized model code with an offline representation of ocean circulation and physical boundary conditions and which allows efficient model integration.

In a complementary effort, Kriest et al. [5] developed an objective framework for the calibration of global biogeochemical ocean models. This framework combines the TMM approach with an estimation-of-distribution algorithm (Covariance Matrix Adaption Evolution Strategy, CMA-ES) and has successfully been applied to both complex and simple three dimensional marine biogeochemical models ([5,11]; HLRN project shk00025). During the last year this calibration framework has been adapted to the code structure of the UVic-TMM [10] and tested on HLRN (HLRN project shk00030). There it has been shown in identical twin experiments that the CMA-ES is able to recover a known parameters set to within a few percent. In parallel a UVic-TMM version with prognostic iron model has been developed building on the work of Nickelsen [7] and Kvale [10], which has already successfully been tested in the calibration framework on the Kiel CAU NEC Linux cluster.

Methods The calibration methods will follow those outlined in [5] and in HLRN project shk00025. We will use a combined framework of UVic+TMM+CMA-ES which has been tested as part of HLRN Project shk00030. Model calibrations will explore the model misfit with respect to global marine observations of oxygen, the macronutrients phosphate and nitrate and, in part, of a global data set of dissolved free iron (Fig. 1). Two different iron-cycle parameterizations of increasing complexity and one model version without iron-cycle parameterization shall be calibrated independently. For the representation of the physical transport, we will use existing UVic ESCM monthly transport matrices [10].

The selection of parameters that can be calibrated given the available global datasets will be based on a careful analysis of sensitivity runs (carried out already on the Kiel CAU NEC cluster) where only single model parameter was varied in each model run. Based on earlier work ([5]; Kvale, pers. comm.) we plan to calibrate between 6 and 8 biogeochemical model parameters in each of the experiments.

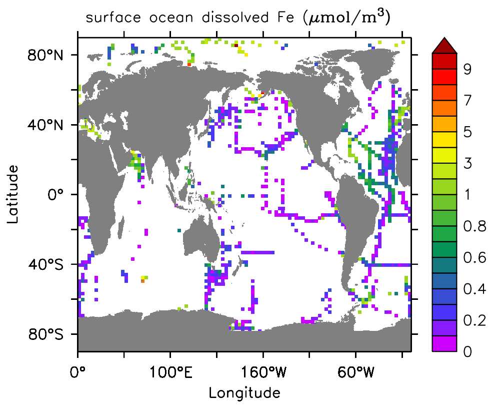

Figure 1: *Surface ocean dissolved iron data*

In model experiments (a) - (c) each of the three model variants will be calibrated against NO_3, PO_4 and O_2 data from the ocean. Collectively these data characterize the imprint of the biological pump on ocean biogeochemistry and, by inference, the marine carbon cycle. The objective of this set of experiments is to determine whether prognostic iron models can offer a better fit to these observations compared to a static iron mask, or even a model without iron.

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More Information

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Funding

Helmholtz Research School for Ocean System Science and Technology (HOSST)