Fully-funded PhD thesis opportunity in Earth system and marine biodiversity modeling

Simulating the impact of a sudden carbon cycle perturbation on climate and marine biodiversity over the last 540 million years

Short summary of the research project

This fully-funded PhD thesis will consist in quantifying the (in)stability of Earth's climate and marine biodiversity in response to an abrupt global carbon cycle perturbation, over the last 540 million years. The candidate will run numerical simulations using the Earth system model of intermediate complexity cGENIE and use the model output to force a marine biodiversity model. They will benefit from a dynamic work environment in a multidisciplinary research unit and develop skills in modeling global biogeochemical cycles and marine biodiversity. Candidates with experience in climate and/or biogeochemical modeling are encouraged to apply. Review of applications and interviews will begin on June 15th and will continue until the position is filled. Targeted starting date is October 1st 2024 but is (relatively) flexible.

Detailed summary of the research project

At the geological time scale, Earth's climate is controlled by the atmospheric CO_2 concentration, which is regulated by strong feedbacks that control Earth's carbon cycle (*1*). This "terrestrial thermostat" is based on the balance of carbon sources and sinks, respectively volcanic CO_2 degassing and the silicate rock weathering, the final result of which is the long-term sequestration of atmospheric CO_2 in the form of carbonate rocks precipitated at the bottom of the oceans. However, on shorter time scales, the terrestrial carbon cycle can undergo significant disruptions. This is the case today due to the massive emission of CO_2 from anthropogenic activities.

Many studies focus on contemporary climate change, the evolution of climate for the centuries to come, and its impacts on human societies and biodiversity. In comparison, the response of the climate system and marine biodiversity to sudden disruptions of the carbon cycle in the geological past remains poorly constrained. This limits our ability to put recent disruptions into perspective.

As part of this doctoral thesis, we will study the response of the climate system and marine biodiversity to sudden disruptions of the carbon cycle during the last 540 million years. If geochemical data make it possible to study this response during specific geological events, such as the Paleocene-Eocene thermal maximum around 56 million years ago, they often only allow the establishment of temporal correlations. Here we will instead choose to use numerical modeling of climate and biogeochemical cycles which, thanks to the experimental approach, will allow us to establish causal relationships and quantify processes.

We will carry out numerical experiments using a coupled climate–biodiversity Earth system model with the aim of quantifying the dependence on the configuration of continents of the response of climate and marine biodiversity to an injection of atmospheric carbon. We will focus on the last 540 million years, which represent the period during which animal life developed in the oceans to give rise to the faunas we know today. We will be particularly interested in the role played by the organic carbon cycle in regulating climate.

The climate component of the model will be the Earth system model of intermediate complexity cGENIE (*carbon-centric Grid ENabled Integrated Earth system model*) (*2*), which offers a representation of climate and ocean biogeochemistry in a spatialized ocean in 3 dimensions. We have previously demonstrated the ability of this model to quantify the response of ocean oxygenation to the changing configuration of continents over the last 540 million years (*3*). The environmental conditions simulated with cGENIE will feed the marine biodiversity model METAL (*MacroEcological Theory on the Arrangement of Life* (*4*)). The METAL model is based on the calculation of the ecological niche – environment interaction and offers a robust representation of current biodiversity (*4*). We have successfully used it to explain spatial and temporal patterns of plankton biodiversity in the very distant past (Ordovician, approximately 450 million years ago) (*5*, *6*). Here we will use an improved version of the model, developed by the candidate, and which will take into account the migration of species in response to climate change. To do this, we will implement a cellular automaton, developed and validated as part of a preliminary study (*7*).

The expected results of the project will improve our understanding of the resilience of climate and marine biodiversity in the face of a major disruption of the carbon cycle. They will shed new light on the (in)stability of environmental conditions over the last 540 million years, and will make it possible to quantify the implications for the evolution of marine communities, in particular through the simulation of extinction rates (*8*).

A strength of this project is its highly interdisciplinary character, at the interface between paleoclimatology, oceanic biogeochemistry, ecology and paleontology. Due to the methods employed, this subject is also profoundly innovative. Numerical modeling of the carbon cycle generally relies on very simplified models that represent the ocean as a single reservoir (*9*). These models do not represent the heterogeneity of the geochemical environments that characterizes the ocean. Here we will use a spatial model to overcome this difficulty thanks to an up-to-date experimental protocol, which will allow us, for example, to simulate in a much more realistic manner primary productivity, the export of organic carbon to depth, its burial in marine sediments, and ultimately the consequences on the carbon cycle and climate. Furthermore, digital models representing the environment-biodiversity interaction have only really emerged over the last ten years. Studies using this type of approach to examine large-scale ecological processes in a mechanistic and quantified manner are still very rare (*10*). The model we will use here offers a robust representation of spatial patterns and in particular of latitudinal gradients of biodiversity.

The candidate will benefit from an optimal work environment, which will guarantee the project the best chance of success. Funding for the thesis and environmental costs (travel, publications) are fully covered by the ANR project CYCLO-SED (2024–2028; PI: A. Pohl). A post-doc recruited for 2 years (09/24 – 09/26) as part of this project will also use the same digital climate model, of which he will improve the representation of continental weathering. The thesis will also benefit from a work dynamic and funding provided by national projects (ANR ECO-BOOST [2023–2026]; current PhD thesis of Alexis Balembois at the LOG laboratory, co-supervised by A. Pohl) and international projects (Leverhulme project led by M. Williams, Univ. Leceister, UK [2023–2026]) relating to different themes of the joint evolution of life and environment during the Phanerozoic. The work planned in this project also aligns well with the research axes that the *Biogéosciences* laboratory aims at developing, in particular the inter-team axis focusing on the "(paleo)environment – biodiversity coupling". Finally, the historical developers of METAL (Grégory Beaugrand – DR CNRS at LOG, UMR 8187, Wimereux) and cGENIE (Andy Ridgwell, Univ. California Riverside) have been collaborators of the supervisors of this thesis for several years and will actively participate in the supervision of this thesis as resource persons.

The candidate will benefit, at the end of the thesis, from a unique profile as a modeler of biogeochemical cycles and marine biodiversity.

References cited (**contribution of at least one of the supervisors*)

1. J. C. G. Walker, P. B. Hays, J. F. Kasting, *Journal of Geophysical Research*. **86**, 9776–9782 (1981).
2. A. Ridgwell *et al.*, *Biogeosciences*. **4**, 87–104 (2007).
3. *A. Pohl *et al.*, *Nature*. **608**, 523–527 (2022).
4. G. Beaugrand, M. Edwards, V. Raybaud, E. Goberville, R. R. Kirby, *Nature Climate Change*. **5**, 695–701 (2015).
5. *A. Zacaï *et al.*, *Science Advances*. **7**, eabd6709 (2021).
6. *D. E. Ontiveros *et al.*, *Nature Communications*. **14**, 6098 (2023).
7. *E. ; Saupe *et al.*, *Nature Geoscience*. **13**, 65–70 (2019).
8. *A. Pohl *et al.*, *Science Advances*. **9**, adg7679 (2023).
9. A. J. Krause *et al.*, *Nature Communications*. **9**, 4081 (2018).
10. *P. Cermeño *et al.*, *Nature*. **607**, 507–511 (2022).

The Biogeosciences research unit

The Biogeosciences research unit is a multidisciplinary research centre in Environmental Sciences gathering more than 150 members, located on the campus of *Université de Bourgogne* in Dijon, at a walking distance from the city centre. Biogeosciences develops research in a wide range of disciplines, including biology, ecology, paleontology, geology and (paleo)climatology. Numerical simulations will use the high-performance computing facilities of the regional cluster of *U. Bourgogne*. The candidate will benefit of the expertise of key project collaborators during stays at other institutions in France (LOG, Wimereux) and the USA (U. California Riverside, Riverside, CA, USA).

How to apply

Candidates with experience in climate and/or biogeochemical modeling are encouraged to apply. Applicants should have solid quantitative and programming skills (notably in Python), as well as good writing skills. Speaking French may be an asset but is not mandatory.

Review of applications and interviews will begin on June 15th and will continue until the position is filled. Targeted starting date is October 1st 2024 but is relatively flexible. To apply, please submit:

i) a cover letter summarizing research interests and expertise;
ii) a CV (including publications and names and contact information for at least two references).

The candidate will be part of Team 'SEDS' and will be supervised by Emmanuelle Pucéat (Professor at *Université de Bourgogne*, Dijon France) and Alexandre Pohl (CNRS researcher, Dijon, France).

Questions and application should be sent to Alexandre Pohl (alexandre.pohl@u-bourgogne.fr) and Emmanuelle Pucéat (emmanuelle.puceat@u-bourgogne.fr).