CENTA

Natural Environment Research Council

Project Proposal Form – 2022 entry

Project Title	**OU5 - Deep ocean circulation dynamics during warm greenhouse climates**
University (where student will register)	The Open University
Which institution will the student be based at?	As above
If other	
Theme (Max. 2 selections)	Climate & Environmental Sustainability ☒ Organisms & Ecosystems ☐ Dynamic Earth ☐
Key words	
Supervisory team (including institution & email address	**PI:** **Philip Holden (The Open University)** philip.holden@open.ac.uk **Co-I:** **Philip Sexton (The Open University)** Philip.sexton@open.ac.uk **Neil Edwards (The Open University)** neil.edwards@open.ac.uk **Dan Lunt (Bristol University)** d.j.lunt@bristol.ac.uk
Is the project co-designed by a student?	Yes ☐ No ☒
Is the PhD suitable for part time study?	Yes ☒ This is a requirement of NERC

Project Highlights:

- Training in development and application of a climate model
- Perform the first transient 3D coupled climate-ocean-carbon cycle simulations across orbital cycles during a greenhouse climate
- Test theories for the sensitivity of deep ocean circulation to orbital cycles in insolation across different background climate states

Overview:

The meridional overturning circulation (MOC) comprises planetary-scale oceanic flows that are of direct importance to the climate system because they transport heat, salt and nutrients meridionally and regulate the exchange of CO_2 with the atmosphere[2]. The MOC, and in particular, the Atlantic's MOC, is now known to have responded very sensitively to orbital forcing across the Pleistocene ice age cycles and played a crucial role in driving Earth into, and out of, these ice ages[2]. Models predict that the Atlantic's MOC could weaken, shoal, or even disappear, in response to ongoing global warming, with profound consequences for regional climate change.

Human-induced CO_2 emissions are projected to elevate atmospheric concentrations of this greenhouse gas to levels that, by the end of this century, will be higher than at any time since the climatic 'greenhouse' of the Eocene epoch (55 to 35 million years ago)[3]. Yet there are no existing geological data with which to determine whether an Atlantic MOC even existed during the Eocene greenhouse or how any MOC may have differed from its modern counterpart, let alone its potential sensitivity to, or role in driving, climatic change at orbital to secular timescales[4]. A major unanswered question is does a 'bipolar seesaw' in interhemispheric water mass competition, akin to that seen across the Pleistocene ice ages[2], exist during an ice-free extreme greenhouse world? Another key question is what processes govern deep water formation dynamics in a greenhouse climate across orbital cycles?

The successful candidate will first run various model experiments with different Eocene palaeogeographies and evaluate which best fits the data (the little that exist from the literature[4], plus exciting new datasets produced in our OU labs). Second, from these results, they will be able to assess what are the Earth system parameters that preclude/permit a bipolar seesaw in deep water formation? Third, by calibrating existing palaeoceanographic datasets to the orbital solutions and integrating these findings with the modelling results, the candidate will explore what processes governed deep water formation dynamics in an Eocene greenhouse climate across orbital cycles. This will also be accomplished for a range of background climate states (e.g. Pleistocene and Pliocene) to provide a comprehensive picture of the controls on deep ocean circulation across contrasting climate states.

Methodology:

This project will apply PLASIM-GENIE, a recently developed intermediate complexity 3D dynamic atmosphere-ocean model with a coupled carbon cycle climate model that has been applied in future[5] and in several paleoclimate studies, extending back to the Eocene[6]. It is significantly more efficient than other models in its class, enabling application to new scientific problems that have been computationally intractable. The project will first involve setting up Eocene model configurations[5] with different ocean gateways[7], and running simulation ensembles that account for orbital variability and model uncertainties. Simulations will be supplemented by well-developed emulation approaches[5,6,7] to calibrate the response, explore the drivers of variability and generate time-series of key Earth system metrics for data-model comparisons.

To establish the precise phasing between the palaeoceanographic data (documenting MOC changes) and orbital cycles, for each epoch (Eocene, Pliocene and Pleistocene) the available datasets will be calibrated to the latest orbital solutions using advanced time series analysis and signal processing software.

Training and skills:

Students will be awarded CENTA2 Training Credits (CTCs) for participation in CENTA2-provided and 'free choice' external training. One CTC equates to 1⁄2 day session and students must accrue 100 CTCs across the three years of their PhD.

Full support will be provided to the student to learn how to install, configure and run complex climate models and analyse their outputs. There will be training in statistical skills, using state-of-the-art approaches in ensemble design and statistical emulation.

Partners and collaboration:

Project results will help meet the ambitious scientific goals of IODP Exp. 342 (from which some of the palaeoceanographic datasets have been generated), and the successful candidate will have opportunities to interact and collaborate with IODP Exp. 342 scientists (http://iodp.tamu.edu/scienceops/expeditions/newfoundland_sediment_drifts.html).

Beyond the Supervisory team, key project collaborators are:
Prof. Heiko Pälike (astronomical age model construction; Bremen, Germany)
Dr Sandra Kirtland-Turner & Prof. Andy Ridgwell (Numerical modelling of ocean circulation during extreme climatic warmth; UC Riverside, USA)

COVID-19 Resilience of the Project:

Covid-19 risks are minimal. The project is fully model-based, with experiments performed on the OU computing cluster, which can be readily accessed via VPN from any good internet connection. Supervisory meetings will be via Microsoft Teams while this remains necessary.

Possible timeline:

Year 1: Literature survey and extraction of published Eocene data and knowledge. Develop Eocene boundary conditions and submit simulation ensembles. Present simulations at a virtual conference.

Year 2: Apply statistical approaches to evaluate paleogeographies that best fit observational data and assess the Earth system parameters that drive variability in deep water formation for publication. Present results at an online conference such as Palaeo PERCS (for early career researchers).

Year 3: Calibrate existing palaeoceanographic datasets and integrate with the modelling results to explore orbital variability of deep water formation dynamics in an Eocene greenhouse climate for a second publication. Present results at an international conference. Write thesis chapters for submission.

Further reading:

1. Westerhold, T. et al., 2020. An astronomically dated record of Earth's climate and its predictability over the last 66 million years. ***Science***, 369, 1383-1387.
2. Adkins, J., 2013. The role of deep ocean circulation in setting glacial climates. ***Paleoceanography***, 28, 539-561.
3. Anagnostou, E., John, E.H., Babila, T.L., Sexton, P.F. et al., 2020. Proxy evidence for state-dependence of climate sensitivity in the Eocene greenhouse, ***Nature Communications***, 11, 4436.
4. Vahlenkamp, M. et al., 2018. Astronomically paced changes in overturning circulation in the Western North Atlantic during the middle Eocene, ***Earth and Planetary Science Letters***, 484, 329-340.
5. Holden, P.B., Edwards, N.R, et al., 2018. Climate-carbon cycles uncertainties and the Paris Agreement, ***Nature Climate Change***, 8, 609-613.
6. Keery, J.S, Holden, P.B, and Edwards, N.R., 2018. Sensitivity of the Eocene climate to CO_2 and orbital variability', ***Climate of the Past,*** 14, 215-238.
7. Thomson, J.R., Holden, P.B., Anand, P., Edwards, N.R., Porchier, C.A. Harris, N.W.B., 2021. Tectonic and climatic drivers of Asian monsoon evolution, ***Nature Communications***, 12, 4022.

Further details:

Please contact Philip Holden (philip.holden@open.ac.uk) for further details.

Applications should include:

- an academic CV containing contact details of three academic references
- a CENTA application form, downloadable from: CENTA application
- and an Open University application form, downloadable from: Home OU application form (if you are resident in the UK) or an Overseas OU application form (if you are an international applicant).

Applications must be sent to **STEM-EEES-PHD@open.ac.uk by Friday 7th January 2022 (12 pm, noon)**