EEES Project Proposal Form – 2021 entry

Project Title	**OU18 - Deep ocean circulation dynamics during warm greenhouse climates**
Key words	Paleoclimate, Eocene, climate modelling
Supervisory team (including email address	**PI:** **Philip Holden** philip.holden@open.ac.uk **Co-I:** **Philip Sexton** Philip.sexton@open.ac.uk **Neil Edwards** neil.edwards@open.ac.uk **Dan Lunt (Bristol University)** d.j.lunt@bristol.ac.uk
Is the PhD suitable for part time study?	Yes ☒ No ☐

Project Highlights:

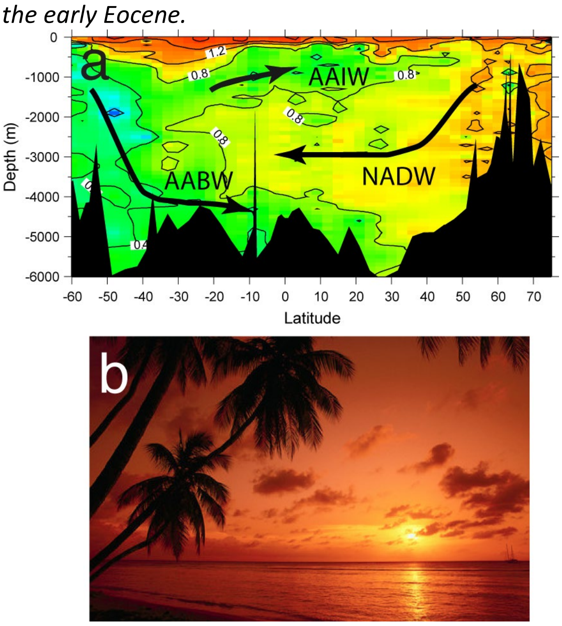
- Training in development and application of a climate model.
- Perform the first transient 3D coupled climate-ocean-carbon cycle simulations across orbital cycles during a greenhouse climate
- Test theories for the sensitivity of deep ocean circulation to orbital cycles in insolation across different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

__Figure 1. a__. Distribution of δ^{13}C in the modern Atlantic (Curry and Oppo, 2005) showing tripartite division of main water masses. NADW – North Atlantic Deep Water, AAIW – Antarctic Intermediate Water, AABW – Antarctic Bottom Water. __b__. Palm trees flourished up into the Arctic circle and on the Antarctic continent in the acute greenhouse warmth of the early Eocene.



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:

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)

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., in review. Tectonic and climatic drivers of Asian monsoon evolution, ***Nature Communications***.

Further details:

Students should have a strong background in physical sciences and enthusiasm for Earth science

If you're not sure whether your academic background is suitable, please contact one of the supervision team or Olivia Acquah at STEM-EEES-PhD@open.ac.uk. We'd be happy to hear from you.

The successful student will join well-established teams researching Earth system science at the Open University.

Applications should include:

- A covering letter that includes:
    - Your motivation to study for a PhD in general
    - Your interest in this project in particular
    - The project-specific skills, aptitude and experience you bring to the project
- an academic CV containing contact details of three references, one of whom should be able to comment on your academic abilities.
- and an Open University application form.
    - If you are British, please use the Home form
    - If you are not British, please use the International form

Applications should be sent to **STEM-EEES-PHD@open.ac.uk** **by 12 noon on Monday 1st March 2021.**