CENTA Project Proposal Form – 2024 entry

Project Title	Reconstructing 30 million years of past climate change
University (where student will register)	The Open University
Which institution will the student be based at?	As above
Theme (Max. 2 selections)	Climate & Environmental Sustainability ☒ Organisms & Ecosystems ☐ Dynamic Earth ☐
Key words	Climate change, paleoclimate, Oligocene, Miocene, climate modelling
Supervisory team (including institution & email address	**PI: Neil.Edwards@open.ac.uk** **Co-I: Philip.Holden@open.ac.uk Luke.Mander@open.ac.uk**
Is the PhD suitable for part time study?	Yes ☒ This is a requirement of NERC

Project Highlights:

- Join a highly interdisciplinary, international group of researchers and modellers working on diverse aspects of climate and Earth system change in the past, present and future
- Develop a unique and powerful computational model to investigate a wide range of questions about past climate change and its impact on species evolution
- Contribute new data and insight with potentially important implications for the critical societal challenges of climate change and biodiversity loss.

Overview:

Climate is a critical driver for the evolution and extinction of species, and existing patterns of terrestrial biodiversity can only be fully explained through the effects of climate variations reaching back tens of millions of years. Over the last 30 million years, a principal driving factor for such change has been the evolution of the Earth's crust, including the rise of the Himalayan-Tibetan and Andes ranges, the slow drift of continents and the opening and closing of ocean gateways between them. Superimposed on these tectonically induced variations are climatic oscillations on timescales of tens to hundreds of millennia driven by cyclical changes in the shape of the Earth's orbit and the resulting growth and decay of the great polar ice caps and ice sheets. On even shorter, decadal to millennial timescales, nonlinear feedbacks internal to the ocean-climate dynamical system can sometimes drive almost equally large variations. At all timescales, the carbon cycle feeds back on these changes, sometimes amplifying and sometimes attenuating the variability by driving changes in atmospheric CO_2.

We know a great deal about past temporal variations in climate from ocean and lake sediment cores, but the spatial variations in climate, from tropical rainforests to arid deserts and mountain and polar ice, are comparably dramatic, and these changes can only be fully described and explained by computer models of the Earth system. Unfortunately, the huge complexity of the system means that projecting and analysing changes over the multi-million year timescales important for species evolution with the spatial detail required to assess the suitability of local habitats that drives that evolution, is effectively impossible using conventional modelling techniques.

This project will build on recently developed techniques that combine conventional Earth system model simulation with a range of spatio-temporal statistical simulation approaches (Holden *et al.* 2019, Thomson *et al.* 2021) to produce integrated reconstructions of Earth's climate change and decadal to millennial variability reaching back tens of millions of years, with the spatial resolution required to understand the effects on biodiversity evolution.

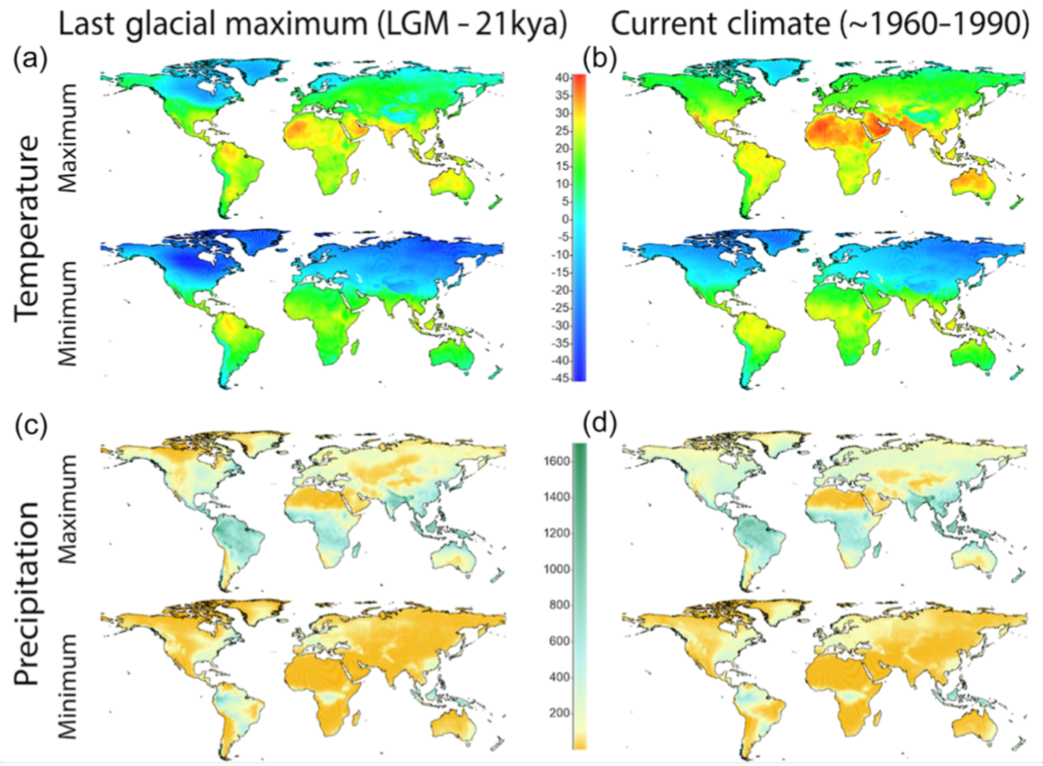

Figure 1: Modelled climate of the Last Glacial Maximum 21,000 years ago from the PLASIM-GENIE model (Holden et al. 2019) compared to data from Hijmans et al. Int. J. Climatol., (2005). Panels (a) and (c) show maximum and minimum temperature and precipitation at the Last Glacial Maximum. Panels (b) and (d) show the corresponding present-day observed climatology. LGM climate is derived by applying modelled change to this present-day climatology. The project will extend simulations with the same model back to 30 million years ago.

Alt text: the panels show colour-coded global maps of maximum and minimum values over land of temperature and precipitation for the glacial and present-day periods respectively. The distributions illustrate the complex spatial structures of these patterns, and the significant difference between past and present patterns, superimposed on the dominant latitudinal variations of the two variables.

Methodology:

A large ensemble of climate simulations will be developed with the intermediate complexity Earth system model PLASIM-GENIE (Holden *et al.* 2016) spanning the range of CO_2, orbital and paleogeographic states relevant to the last 30 million years. Paleogeographic inputs will come from simulations carried out by collaborators in the University of Sydney. The climate simulations will be used to construct a stochastic model, or emulator, of the climate response to arbitrary input conditions, by decomposing the climate into a series of characteristic spatial patterns. The emulator will then be used to reconstruct global climate over many millions of years at very low computational cost. Modes of internal variability on shorter timescales will be incorporated into the emulator using techniques that preserve simulated climate variance. Finally, simplified representations species evolution will be used to infer potential impacts on changing patterns of biodiversity.

Training and skills:

All Faculty PhD students will be provided with extensive training opportunities through the Open University graduate school and STEM Faculty programmes including core research and outreach skills in the first year and more specifically targeted training needs at later stages. This will include training in communicating their research to a range of different audiences, through a range of channels from academic publication to social media.

The student will also receive training in using the PLASIM-GENIE Earth system modelling framework; in statistical emulation using Gaussian Process models; and other numerical, statistical, or data processing methods required for the project. These are likely to include: experimental design for computer experiments, Bayesian calibration, R statistical software and data visualisation.

Partners and collaboration (including CASE):
Sabin Yahirovic in the University of Sydney is an expert on modelling tectonic evolution of the Earth's crust and will collaborate on supplying paleogeographic inputs to the climate models.

Thiago Rangel at the Federal University of Goiás in Brazil is an expert on modelling the evolution of biodiversity, and will collaborate on estimating the potential effects of long-term climate variability on species evolution in the final stage of the project.

Possible timeline:

Year 1: tasks. Setting up and running Oligocene, Miocene and Pliocene climate model simulations and validating output projections against existing observational data and model simulations from the literature.

Year 2: tasks. Constructing statistical framework for spatio-temporal emulation of the climate simulations and incorporation of shorter-term variability, construction of the long-term climate model emulator. Preparation of manuscripts describing paleoclimate simulations for publication.

Year 3: tasks. Creating long-term climate reconstructions with the emulator and developing a simplified methodology to estimate potential effects on species evolution; presenting results at international conferences; writing up results for thesis and further publishable papers.

Further reading:

Holden, Philip B.; Edwards, Neil R.; Fraedrich, Klaus; Kirk, Edilbert; Lunkeit, Frank and Zhu, Xiuhua, (2016) PLASIM–GENIE v1.0: a new intermediate complexity AOGCM, Geoscientific Model Development, 9 pp. 3347-3361

Holden, Philip B.; Edwards, Neil R.; Rangel, Thiago F.; Pereira, Elisa B.; Tran, Giang T. and Wilkinson, Richard D. (2019) PALEO-PGEM v1.0: a statistical emulator of Pliocene–Pleistocene climate Geoscientific Model Development, 12(12) pp. 5137-5155

Thomson, James R.; Holden, Philip B.; Anand, Pallavi; Edwards, Neil R.; Porchier, Cécile A. and Harris, Nigel B. W. (2021) Tectonic and climatic drivers of Asian monsoon evolution Nature Communications, Article 4022(12)

Further details:

Please contact Prof. Neil Edwards (Neil.Edwards@open.ac.uk) for further details.