The ice age, oceans and climate: triggers of iceberg calving and rapid temperature change

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This PhD project will use numerical modelling in order to establish the complex chain of events that took place early in the last deglaciation, linking catastrophic ice sheet collapse, iceberg armadas, rapid cooling, abrupt warming and the complete reorganisation of largescale Atlantic Ocean circulation. The candidate will explore possible mechanisms that link these different parts of the earth system, undertaking high profile research to examine existing hypotheses and create news ones to understand the cause and consequences of rapid climate change in the high latitudes.

Photo credit: HC Ng, 2018

At the Last Glacial Maximum (21,000 years ago), vast ice sheets stretched across much of the Northern Hemisphere, covering large expanses of North America, Greenland and Eurasia. As climate warmed, and the ice sheets began retreating, an intriguing chain of events was triggered in the North Atlantic. Largescale ocean circulation slowed, climate cooled, armadas of icebergs were released, ocean circulation rapidly strengthened and temperatures abruptly rose. Although well documented individually (Heinrich Stadial 1, Heinrich Event 1, the Bølling Warming), it remains unknown precisely *how* and even *if* these events were linked. Two recent studies (Ivanovic et al., 2018; Ng et al., 2018) put forward the tentative hypothesis that melting of the Eurasian ice sheet caused ocean circulation to slow-down, cooling the North Atlantic region and triggering enhanced iceberg calving from the Eurasian ice sheet. This amplified the initial change, increasing iceberg production from North America and sustaining the cooling. But, this chain of events has never been tested. Furthermore, it remains unclear what caused the last of these events; the abrupt Bølling Warming. Was it a rapid reduction in the amount of meltwater reaching the ocean (e.g. Liu et al., 2009)? Was a critical threshold in atmospheric CO_2 crossed (e.g. Zhang et al., 2017)? Or was it simply the result of an inherently unstable climate regime (e.g. Klockmann et al., 2018; Peltier and Vettoretti, 2014)?

The last deglaciation is the best documented period of abrupt climate change, yet we do not understand how and why the recorded events took place. This exciting project tackles this challenge, testing ice-ocean-atmosphere interactions to produce seminal new knowledge of our climate.

Please contact the lead supervisor (r.ivanovic@leeds.ac.uk) for more information and before applying.

Project Aim

The candidate will run complex numerical climate and ice sheet models to examine the interplay between climate, icebergs and ocean circulation in the early period of the last deglaciation (21-14.5 thousand years ago). The overall aim is to establish the chain of events surrounding Heinrich Stadial 1, involving ice sheet melting, a rapid slowdown of the largescale Atlantic Ocean circulation (Atlantic Meridional Overturning Circulation, AMOC), North Atlantic cooling, enhanced iceberg discharge from the Eurasian and North American ice sheets (Heinrich Event 1), a resumption of the AMOC and abrupt warming (Bølling Warming).

Examples of research questions to be addressed

It is expected that the project will evolve in line with the best research on the topic. The student will be fully supported to follow their interests and make the project their own. Here is an example of the direction the PhD could take:

Chapter/paper 1: Establishing the trigger for Heinrich Stadial 1

- Is it possible to improve simulations of the Last Glacial Maximum oceans, e.g. by retuning the model?
- What is the best scenario of ice sheet evolution during the early last deglaciation?
- Did rapid deglaciation of the Barents-Kara Sea region drive a slowdown in Atlantic Ocean circulation 19-18 thousand years ago?
- Does the initial condition of the climate and ocean control their response to meltwater?

Chapter/paper 2: Understanding the cause of enhanced iceberg calving

- Did Atlantic Ocean subsurface warming enhance rates of iceberg calving?
- What was the relationship between Eurasian and North American iceberg calving?
- How did freshwater from melting icebergs influence ocean circulation?
- Was there also a role for the thermal heat flux from icebergs?

Chapter/paper 3: A better knowledge of abrupt warming

- Was the Bølling Warming a forced event or a product of internal climate instability?

International Network

The candidate will have the opportunity to benefit from and feed directly into:

- The Paleoclimate Model Intercomparison Project (PMIP), for which the lead-supervisor and co-supervisor are working group leaders [https://pmip4.lsce.ipsl.fr]
- CLIVAR (a World Climate Research Programme initiative) Atlantic Regional Panel, for which the lead-supervisor is a panel member [http://www.clivar.org/]

Potential for high-impact research

This exciting and novel work employs recent, ground-breaking developments in our knowledge of climate-ice-ocean interactions. Mechanisms of iceberg calving will be tested, as well as their influence on ocean circulation and climate, using the best documented instances of these processes having been triggered in the past. The student will develop a highly sought-after, multidisciplinary skill-set, contributing towards the development of an interdisciplinary field of research that is at the forefront of climate science. By the nature of this work, and due to its timeliness, there is strong potential for the PhD candidate to influence the direction of international research being carried out on this theme, and to thus establish a world-renowned reputation for innovative science.

Training, support and research opportunities

This project affords many exciting opportunities for skills and research development, in particular:

- Joining a team of climate scientists working on related and different aspects of past, present and future climate and ocean circulation change.
- Working within the dynamic and multidisciplinary Physical Climate Change and Palaeo@Leeds research groups, in the Institute for Climate and Atmospheric Studies and Earth Surface Science Institute.
- Using state-of-the-art research facilities including high-performance computer clusters (Polaris N8 and ARC) at the University of Leeds.
- Developing high-tech computer programming, model output processing and data visualisation skills, with the support of the Centre of Excellence for Modelling the Atmosphere and Climate and other research scientists across the School of Earth and

Environment (Leeds) who have a long track record of training highly successful PhD students with limited prior knowledge of computing.

- Collaborating with world-leading experts in climate research through the Paleoclimate Modelling Intercomparison Project (PMIP) and CLIVAR Atlantic Region Panel.
- Attending and presenting results at major, international conferences, e.g. AGU (San Francisco, New Orleans), Goldschmidt (Hawaii, Lyon, Barcelona) and EGU (Vienna).
- Attending residential summer-schools (e.g. in Italy, USA, UK) and project-specific in-house workshops/courses.
- Other more generalised training through the Leeds-York Doctoral Training Partnership and a wide portfolio of University of Leeds training programmes.

Full-support for all technical and scientific aspects of the project, including the model development work, will be provided in-house (Leeds) and by external collaborators. With this training, the student will be well equipped to pursue their own research interests.

Entry requirements

A good first degree (1 or high 2i), Masters degree or equivalent in a physical or mathematical discipline; such as Physics, Mathematics, Oceanography, Meteorology, Climate Sciences, Earth/Environmental/Geographical Sciences, Chemistry, Engineering or Computer Sciences. Some experience of computer programming is highly desirable e.g. in Fortran, C++, Python, MATLAB, IDL or R etc...

Further information

Specific background literature:

Ivanovic, R.F., Gregoire, L.J., Burke, A., Wickert, A.D., Valdes, P.J., Ng, H.C., Robinson, L.F., McManus, J.F., Mitrovica, J.X., Lee, L., Dentith, J.E., 2018. Acceleration of northern ice sheet melt induces AMOC slowdown and northern cooling in simulations of the early last deglaciation. Paleoceanography and Paleoclimatology 33, 807–824. https://doi.org/10.1029/2017PA003308

Klockmann, M., Mikolajewicz, U., Marotzke, J., 2018. Two AMOC states in response to decreasing greenhouse gas concentrations in the coupled climate model MPI-ESM. J. Climate. https://doi.org/10.1175/JCLI-D-17-0859.1

Liu, Z., Otto-Bliesner, B.L., He, F., Brady, E.C., Tomas, R., Clark, P.U., Carlson, A.E., Lynch-Stieglitz, J., Curry, W., Brook, E., Erickson, D., Jacob, R., Kutzbach, J., Cheng, J., 2009. Transient Simulation of Last Deglaciation with a New Mechanism for Bølling-Allerød Warming. Science 325, 310–314. https://doi.org/10.1126/science.1171041

Ng, H.C., Robinson, L.F., McManus, J.F., Mohamed, K.J., Jacobel, A.W., Ivanovic, R.F., Gregoire, L.J., Chen, T., 2018. Coherent deglacial changes in western Atlantic Ocean circulation. Nature Communications 9, 2947. https://doi.org/10.1038/s41467-018-05312-3

Peltier, W.R., Vettoretti, G., 2014. Dansgaard-Oeschger oscillations predicted in a comprehensive model of glacial climate: A “kicked” salt oscillator in the Atlantic. Geophys. Res. Lett. 41, 2014GL061413. https://doi.org/10.1002/2014GL061413

Zhang, X., Knorr, G., Lohmann, G., Barker, S., 2017. Abrupt North Atlantic circulation changes in response to gradual CO2 forcing in a glacial climate state. Nature Geosci 10, 518–523. https://doi.org/10.1038/ngeo2974

Broader background literature:

Clark, P.U., Shakun, J.D., Baker, P.A., Bartlein, P.J., Brewer, S., Brook, E., Carlson, A.E., Cheng, H., Kaufman, D.S., Liu, Z., Marchitto, T.M., Mix, A.C., Morrill, C., Otto-Bliesner, B.L., Pahnke, K., Russell, J.M., Whitlock, C., Adkins, J.F., Blois, J.L., Clark, J., Colman, S.M., Curry, W.B., Flower, B.P., He, F., Johnson, T.C., Lynch-Stieglitz, J., Markgraf, V., McManus, J., Mitrovica, J.X., Moreno, P.I., Williams, J.W., 2012. Global climate evolution during the last deglaciation. PNAS 109, E1134–E1142. https://doi.org/10.1073/pnas.1116619109

Ivanovic, R.F., Gregoire, L.J., Kageyama, M., Roche, D.M., Valdes, P.J., Burke, A., Drummond, R., Peltier, W.R., Tarasov, L., 2016. Transient climate simulations of the deglaciation 21–9 thousand years before present (version 1) – PMIP4 Core experiment design and boundary conditions. Geosci. Model Dev. 9, 2563–2587. https://doi.org/10.5194/gmd-9-2563-2016

YouTube videos: Reconstructing climate history and drivers of ocean circulation