Deciphering the dynamics of abrupt ocean change and climate tipping points

Undertake a PhD exploring fundamental ocean and climate dynamics as part of a UK-wide project investigating early warning systems of abrupt climate change

Supervisory team

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Outline project description

Is it possible to radically alter the way that the ocean moves? Could we be doing this through global warming? Is there any way of knowing when such changes will take place?

The ocean plays a crucial role in our climate by helping to establish global patterns of temperature and rainfall. This is achieved by the large-scale circulation, which moves heat around in vast quantities, transporting it from equatorial regions towards the high latitudes. Without such circulation, our planet – and our local climates – would look radically different to how they do today.

Evidence from the geological past suggests that in fact the ocean circulation could have been radically different in the past to what it is like today. Indeed, it's possible that the vigorous circulation that moves heat around and helps establish our climate was much slower and more sluggish in the past. What's more, some lines of argument propose that we could be pushing the ocean into such a state through human-induced global warming; a so-called "tipping event" that, if it were to happen, would have widespread humanitarian consequences.

The ocean's potential to rapidly switch into another state – a behavior known in dynamical systems as bistability – has been explored in both simple and complex climate models. However, questions remain about whether such models accurately represent the most crucial characteristics of such behavior. It yet remains unclear whether they can be trusted to reveal either the dynamic nature of past changes or the possibility of future tipping events.

This ambitious PhD will focus on understanding the fundamentals of ocean bistability and tipping events. It will involve developing and exploring simple ocean and climate models grounded in our best physical understanding. These models will be interrogated to understand the controls on ocean tipping events and to determine whether they display evidence of "early warnings" through which the occurrence of an event can be predicted prior to it happening. The model will subsequently be used to understand the behavior of the ocean under vast changes that have happened in the geological past, and to consider the likelihood and mechanisms of future changes under global warming.

Broader project

This PhD is part of the Advanced Research and Innovation Agency (ARIA) project **VERIFY: Out Of Sample Testing For Early Warning Systems Using Past Climate**. VERIFY's overall aim is to observe and understand massive changes in the climate of the North Atlantic, namely the Greenland Ice Sheet and Subpolar Gyre, in the recent and geological past. Embedded in 6 institutions across the UK, and with partners in mainland Europe and the USA, VERIFY brings together experts in modern and paleo-climate dynamics, high resolution and complexity modelling, with data scientists and statisticians. The project will develop Digital Twins of past tipping events, which will serve as a testbed for verifying whether tipping behavior can be predicted by Early Warning Systems (EWSs), forming a crucial component of an £81m ARIA-funded effort to develop these systems in the North Atlantic region. The work of this PhD will form a crucial aspect of the project's hierarchy, developing computationally efficient, physically interpretable models to interrogate past and future tipping. As part of this project, the student will benefit from interactions with researchers and fellow students across VERIFY and the wider ARIA 'Forecasting Tipping Points' programme.

Indicative timeline

The student will have freedom to explore the above problem in a manner guided by their curiosity, but the following timeline is suggested:

Year 1. Build understanding of the ocean and climate system, and the occurrence and characteristics of bistability and tipping behavior. Develop a conceptual model of the large-scale ocean circulation based on our most up-to-date understanding of the fundamental dynamics of the system. Interrogate that model for features of bistability and investigate the conditions under which tipping is plausible and likely.

Year 2. Interrogate the model in the context of past ocean change. Explore the capacity of the simplified model to reproduce observed past ocean behavior and the behavior simulated in more complex climate model simulations.

Year 3. Use the model, and the basic physical understanding derived from it, to investigate ensemble spread in simulations of past tipping behavior following a recently developed statistical approach. Leverage this approach to make predictions of the likelihood of a tipping event under a future global warming scenario.

Year 4. Write up and submit thesis.

Throughout the PhD, the student will write up and publish their results in academic journals and attend conferences to present their work, integrating them within the research community and alerting the community to their work. Additionally, they will attend summer schools on one or two occasions to continually enhance and broaden their learning and to develop relationships with their peers.

Supervision arrangements

The student will be based at the University of St Andrews throughout the project but will have opportunities for extended visits with supervisors at University College London, particularly during the latter half of the PhD. They will thus benefit from a breadth of expertise perfectly suited to supporting this research project. At the University of St Andrews, expertise in ocean and climate dynamics – including conceptual model frameworks – is offered by Dr MacGilchrist and complemented by Dr Rae, who has extensive understanding of past ocean change. At University College London, Dr Brierley and Dr Chandler have pioneered statistical approaches to understand both past and future climate change. They have a wealth of expertise in quantitatively bringing together observations, theory, and complex model data to improve predictions of future climate change. As well as dedicated supervisory meetings and regular meetings with the Ocean Dynamics group in St Andrews, the student will benefit from attending the established bi-weekly COASt (Climate, Oceans, and Atmosphere @ St Andrews) meetings – an informal environment where they will enjoy frequent interactions with their St Andrews supervisors, as well as numerous students and postdoctoral researchers working on related problems.

Application details

Deadline: Monday 10th March 2025.

Candidates will be invited for interview shortly after the application deadline. Offers will be made prior to the NERC Universal Acceptance Date on 19th March.

Eligibility: Please note that the funder covers stipend and home fees only – international students will need to secure additional funding to cover the difference between home and international fees themselves. The project will assist with applications for additional funding for exceptionally strong international students.

For further details on how to apply, see here. For informal enquiries and further information, please contact Graeme MacGilchrist (gam24@st-andrews.ac.uk).

Further reading

Boers, N., 2021. Observation-based early-warning signals for a collapse of the Atlantic Meridional Overturning Circulation. Nat. Clim. Chang. 11, 680–688. https://doi.org/10.1038/s41558-021-01097-4

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Melcher, J.O., Halkjær, S., Ditlevsen, P., Langen, P.L., Vettoretti, G., Rasmussen, S.O., 2025. A novel conceptual model for Dansgaard–Oeschger event dynamics based on ice-core data. Climate of the Past 21, 115–132. https://doi.org/10.5194/cp-21-115-2025

Stommel, H., 1961. Thermohaline Convection with Two Stable Regimes of Flow. Tellus 13, 224–230. https://doi.org/10.1111/j.2153-3490.1961.tb00079.x

Zimmerman, C.C., Wagner, T.J.W., Maroon, E.A., McNamara, D.E., 2025. Slowed Response of Atlantic Meridional Overturning Circulation Not a Robust Signal of Collapse. Geophysical Research Letters 52, e2024GL112415. https://doi.org/10.1029/2024GL112415