Modelling rapid CO$_2$ and climate change in the Southern Ocean

Supervisory Team

- **Dr Andrea Burke**, School of Earth and Environmental Sciences
- **Prof David Dritschel**, School of Mathematics and Statistics
- **Dr James Rae**, School of Earth and Environmental Sciences
- **Dr Jean Reinaud**, School of Mathematics and Statistics

Key Words

Southern Ocean, climate, carbon, dynamical modelling

Funding and Notes

Funded by the University of St Andrews via St Leonard's College, The School of Earth and Environmental Sciences, and the School of Mathematics and Statistics

**Deadline: 1 PM, March 19th 2019**

Eligibility: All UK/EU citizens who meet St Andrews entry requirements are eligible for fee costs and a full-stipend

Project Description

The Southern Ocean plays a fundamental role in the regulation of Earth’s climate through its uptake of heat and carbon. Despite representing only 20% of the ocean surface area, it accounts for more than 50% of ocean carbon uptake and more than 75% of ocean heat uptake (Charrassin et al., 2008; Meredith and Hogg, 2006). The reason for the Southern Ocean’s disproportionately large impact on the climate system is its intimate link to the deep ocean. This is driven by its unique dynamics, with strong westerly winds and surface buoyancy forcing driving a divergent surface flow, which brings deep (~2000 m) water to the surface, allowing heat and carbon exchange with the atmosphere. These winds and buoyancy forcing also generate the world's largest current system – the Antarctic Circumpolar Current – which transports heat and carbon between the major ocean basins. Despite the importance of the Southern Ocean for climate and carbon cycling, the dynamical understanding of this region is weak, with state-of-the-art climate models consistently showing biases and unrealistic depictions of physical and biogeochemical processes. How the Southern Ocean will respond dynamically to a warming climate, and the implications of those changes on the carbon cycle, represent major uncertainties in our projections of future climate change.

Because of the lack of long term oceanographic measurements in this remote region, our best constraints on Southern Ocean circulation and biogeochemistry under different climate conditions come from the geological record. Using geochemical measurements on sediments cores (Anderson et al., 2009) and deep-sea corals (Burke and Robinson, 2012), it has been shown that changes in Southern Ocean chemistry are closely coupled to atmospheric CO$_2$ rise at the end of the last ice age (20,000 years ago). Recent work (Rae et al., 2018) demonstrates that such changes may even occur on centennial timescales, synchronous with abrupt jumps in atmospheric CO$_2$ and rapid warming at high Northern Latitudes (10 °C in 10 years). However despite progress in modelling Southern
Ocean circulation and carbon cycling under steady-state conditions (Burke et al., 2015; Ferrari et al., 2014), efforts to place transient changes in Southern Ocean circulation into a robust dynamic framework are in their infancy. This impacts our ability to understand both past ice age climates and fast feedbacks under future global warming.

**This PhD studentship will transform our understanding of the Southern Ocean's role in rapid CO$_2$ and climate change using novel dynamical modelling.** The essential aspects of Southern Ocean dynamics will be represented in a new model of the ocean's overturning circulation. This model will be based on a framework (Fig. 2) that has been developed to capture the balance between winds and eddies that sets Southern Ocean tracer transport and that can be run efficiently under different boundary conditions. Recent application of similar models have led to several high impact studies (e.g. Burke et al., 2015; Ferrari et al., 2014). However these efforts have been run only at steady state and have no representation of climate feedbacks or carbon cycling. This project will develop this modelling approach to allow rapid climate events to be explored. Specifically the student will:

- develop numerical methods to permit the study of the time-evolving coupled climate system;
- assess the impact of different parameterisations of eddy dynamics and diapycnal diffusivity;
- add key climate and biogeochemical feedbacks.

This will allow the student to address fundamental questions about the Southern Ocean's role in the climate system, including:

- the role of Southern sea ice in setting the global overturning circulation;
- the potential of the Westerly winds to drive transient circulation and CO$_2$ outgassing anomalies;
- the response of the Southern Ocean to rapid climate change in the Northern Hemisphere.

**Ultimately this work will improve understanding of the Southern Ocean's behaviour during rapid climate change and will help develop predictive models of future heat and CO$_2$ exchange in this crucial region.**

![Figure 2: from Burke et al., 2015. A conceptual model of the ocean’s overturning circulation. The thick arrows indicate mass transports, and thin curvy arrows indicate the directions of buoyancy fluxes. The green and yellow arrows correspond to lower and upper overturning cells, respectively. The dynamic model proposed here will capture these essential features of the ocean circulation in a flexible mathematical framework informed by the latest understanding of fluid dynamics, and explore its behavior under different climate states.](image)

**Training & Skills**

This St Leonard’s College Interdisciplinary studentship will provide training in climate science, dynamical modelling, numerical methods, oceanography, biogeochemical cycling, and paleoceanography/paleoclimatology. The student will be a member of both the Climate and Global Change research group in the School of Earth and Environmental Sciences and the Vortex Dynamic research group in the School of Mathematics and Statistics, with desk space in both Schools. In addition to the specific training received through the PhD, the student will have the opportunity to improve general transferrable skills through University courses run by CAPOD, external research workshops, and presentations at group meetings. The student will also have the opportunity to attend and present their research at national conferences, and at least one international conference.
References & Further Reading
Ferrari et al. (2014). PNAS 111, 8753–8758. doi:10.1073/pnas.1323922111
Jansen (2017), PNAS 114, 45-50. doi: 10.1073/pnas.1610438113

Further Information
For further information, please contact:
Dr Andrea Burke
School of Earth and Environmental Sciences
University of St Andrews
+44 (0)1334 464015
ab276@st-andrews.ac.uk

The University of St Andrews is committed to promoting equality of opportunity for all and has a series of University wide diversity awards including the Athena SWAN Institutional Bronze Award, the European Commission HR Excellence in Research Award and the LGBT Charter, see http://www.st-andrews.ac.uk/hr/edi/diversityawards/
We welcome applications from women, persons of colour and persons with disabilities. You can find out more about Equality and Diversity in the University at http://www.st-andrews.ac.uk/hr/edi/