The Southern Ocean’s role in CO2 change

Curious12

Global Environmental Change

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Overview

The cause of glacial-interglacial CO2 change has been described as the â€œholy grailâ€ of palaeoclimate. Several decades of research have narrowed focus onto the Southern Ocean as the most important driver of glacial interglacial CO2 change (Sigman et al., 2010), due its intimate link to the deep ocean (Rae & Broecker, 2018) and its unique biogeochemistry: as a high nutrient low-chlorophyll region, CO2 brought to the surface from deep upwelling cannot be efficiently captured by biological productivity and may outgas to the atmosphere.

Several mechanisms have been proposed to explain how the Southern Ocean may have trapped more CO2 during glacials, including iron fertilisation, ocean stratification, and a â€œlidâ€ of increased sea ice. However while various tracers of these processes exist it has, until recently, not been possible to quantitatively assess their impact on CO2 storage and release.

The aim of this project is to quantify the role of the Southern Ocean in CO2 change over the last ice age, including the glacial-interglacial CO2 changes that help drive the ice ages themselves, and the CO2 excursions associated with rapid climate change. To do this we will use the boron isotope composition of fossil carbonates (Foster & Rae, 2016, Rae 2018) to reconstruct how Southern Ocean pH and CO2 changed over glacial cycles.

The student will make the first high-resolution pH and CO2 reconstructions from the Antarctic Zone of the Southern Ocean, using novel analytical approaches to overcome small sample sizes. These will be coupled with new records of CO2 storage and release in the deep Southern Ocean over the last glacial cycle.

By comparing these data to multi-proxy records of biological pump efficiency, sea ice, and ocean circulation, alongside experiments with an Earth system model, we will work out the relative importance of these processes in CO2 change on glacial-interglacial to centennial timescales.

Supervisory Team

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Key Words

- Southern Ocean
- CO2
- Palaeoceanography
- Biological productivity

- Ocean circulation

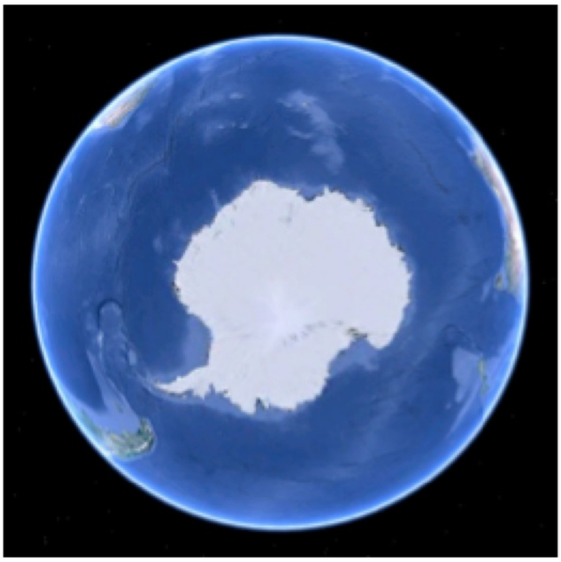

Figure 1: The Southern Ocean plays a crucial role in CO_2 and climate change.

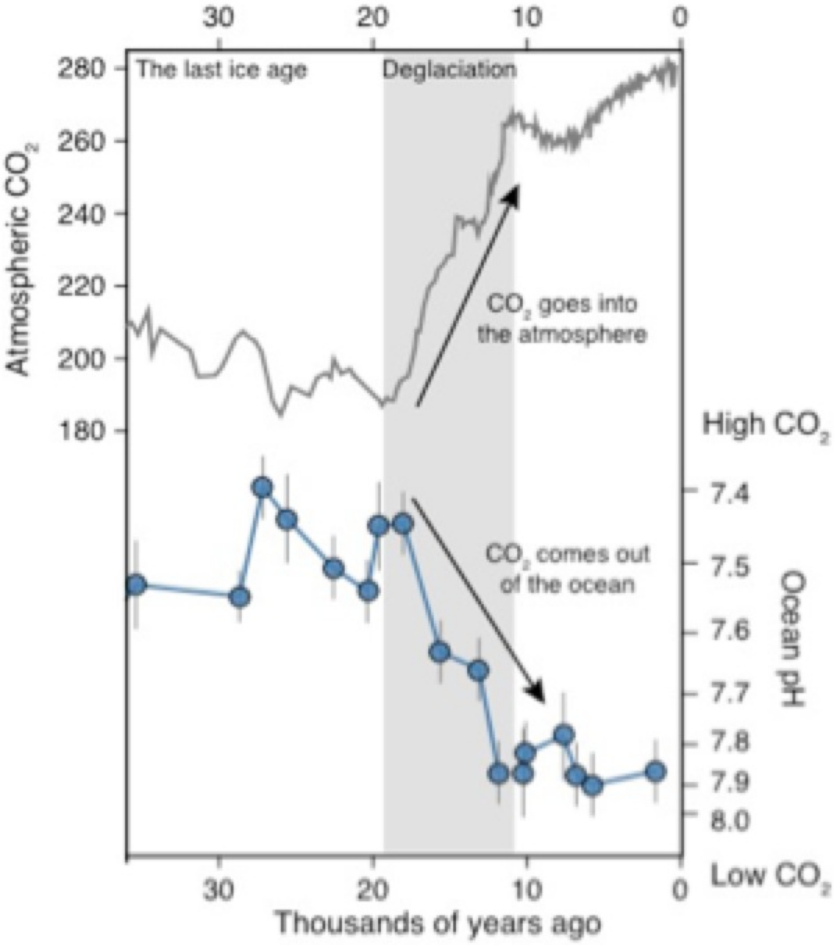

Figure 2: Deep Southern Ocean pH and CO_2 reconstruction based on boron isotopes in deep sea corals shows a mirror image pattern to atmospheric CO_2 change. Adapted from Rae et al., 2018.

Methodology

The STAiG lab has a strong track record in the use of boron isotopes to reconstruct pH and CO2, with recent high profile results including the most direct evidence to date of CO2 release from the deep Southern Ocean (Figure 2; Rae et al., 2018) to the upper ocean and the atmosphere (Martinez-Boti et al., 2015), and constraints on iron fertilisation versus circulation change on ocean CO2 outgassing in the North Pacific (Gray et al., 2018).

We will apply this same approach to planktic and benthic foraminifera in sediment cores from the polar and subpolar regions of the Southern Ocean, to reconstruct CO2 drawdown in the surface ocean and storage in the abyss. Thanks to recent analytical developments in the STAiG lab at the University of St Andrews, it is now possible to analyse the small numbers of forams often found in these cores to high precision, and we will pursue novel approaches to further push the limits of this method.

We will generate records spanning the last glacial cycle, but with increased resolution over rapid CO2 and climate change events. Material is made available through partnership with the British Antarctic Survey and Scripps Institute of Oceanography, alongside ongoing collaboration with the Alfred-Wegner Institute for Polar Research. The student will undertake sampling trips to these institutes, and may also partake in a research cruise.

Results will be compared to carbon cycle model experiments (e.g. Bauska et al., 2016; Rae et al., 2014) to constrain the role of different processes in driving net CO2 change in the atmosphere. Depending on the interest of the student this modeling component can be expanded, or they may instead investigate coupled measurements on other geochemical tracers, including silicon and nitrogen isotopes.

Project Timeline

Year 1

Literature review, sediment core sampling, sediment processing, foraminifera picking/counts, training and further development of clean laboratory methods and mass spectrometry, initial boron isotope and trace element measurements.

Year 2

Generation of boron isotope records, and draft initial paper(s)

Year 3

Finalize data sets, extending records in space and time. Paper submission.

Year 3.5

Write thesis and submit final papers.

Training & Skills

The student will gain specific training in boron isotope analysis, mass spectrometry, micropaleontology, and clean lab chemistry, as well as training and expertise in climate science and oceanography. The student may also engage with numerical climate modelling and inverse techniques if interested. Furthermore, over the course of the PhD, the student will gain transferable skills such as scientific writing, statistics and data analysis, and problem-solving, as well as time management and working towards a long-term goal.

References & further reading

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Further Information