Groundwater under Antarctica: Ice sheets, Carbon, and Oceanography (GAICO)

Impact of deep subglacial groundwater on Antarctic ocean and carbon circulation

Supervisory team

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Outline project description

Groundwater—water stored within and moving in and out of permeable rock and soils—plays a major role in the global water cycle. Recently, its bulk movement from land to ocean, and associated mobilisation of carbon, has been found to be much more important for the global carbon cycle than previously considered. Although groundwater is known to move dynamically between the Earth surface and its underlying sedimentary layers, in the polar regions, groundwater is still commonly assumed to be completely isolated from the surrounding air, water, and ice sheets. Yet, recent geophysical surveys find groundwater underlying the Greenland and Antarctic ice sheets to be pervasive and dynamic (Figure 1), and may contribute up to a third of the freshwater flux entering the surrounding Polar Oceans. **Overlooking the contribution of ice sheets to groundwater discharge therefore significantly underestimates its total contribution of both water and carbon cycles, impacting both sea level rise and global carbon estimates.**

The subsequent export of fresh meltwater from the Antarctic ice sheet to the surrounding ocean not only contributes to sea level rise, but also impacts the regional and large-scale ocean circulation in the surrounding Southern Ocean. These circulation patterns in turn upwells stored carbon at the seafloor. **Reconsidering how meltwater and continental carbon enters the surrounding oceans via both subglacial and groundwater pathways will undoubtedly reframe our understanding of how the Antarctic ice sheet interacts with the surrounding oceans, which have to date assumed no groundwater discharge.**

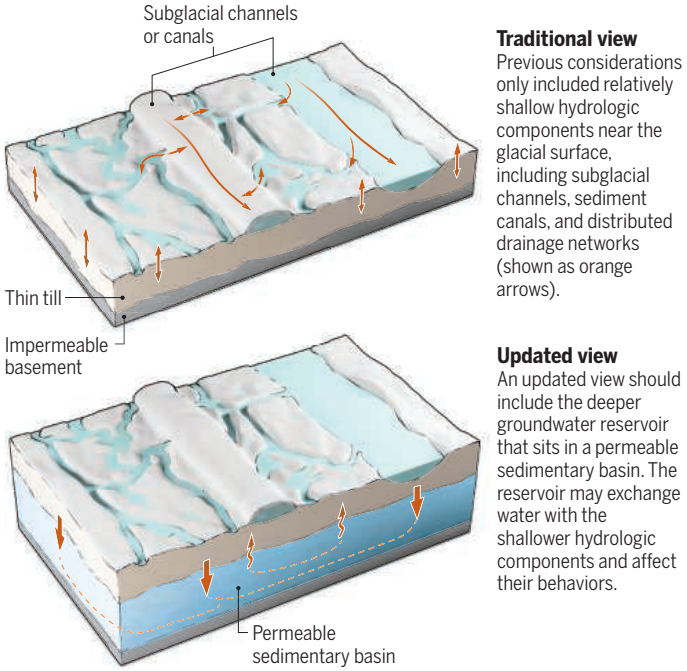

Figure 1: Challenging traditional viewpoints of groundwater and glacier meltwater interactions. From Chu et al. (2022)

The objective of this PhD project is to examine and reconsider the water and carbon cycle of the Antarctic continent to account for ice sheet-groundwater dynamics. To achieve this objective, the component aims of the project are to:

- Model the distribution of water and carbon exported from the Institute Ice Stream system to surrounding embayments;
- Examine the changes that increased groundwater export has on regional ocean circulation; and
- Understand how the increased water and carbon export will modulate the physical and biogeochemical dynamics of the wider Antarctic ocean.

This PhD project is likely to fundamentally reframe our understanding of how water and carbon is transported from ice to ocean via expansive groundwater pathways, as well as addressing a significant component of the regional water and carbon budget that has to date been ignored. To address these component aims, the PhD will leverage a combination of theoretical frameworks, process-based ice sheet and oceanographic models, idealised simulations, and observational datasets. Though the exact course of events will be organically shaped by the successful candidate's academic background, research interests, and technical strengths, the project supervisors envision the following timeline:

Year 1: Extend traditional groundwater dynamical frameworks to incorporate meltwater infiltration from the overlying Antarctic ice sheet. Incorporate this framework in a numerical ice flow model to couple ice sheet dynamics to the groundwater environment. Attend an introductory ice sheet modelling course to enhance capacity building.

Year 2: Progress and refine the coupled ice sheet-groundwater flow model to produce estimates of groundwater discharge at ice sheet margins. Using these estimates as source inputs, explore how varying the spatial distribution of meltwater influx into the surrounding oceans will modify the regional ocean circulation through oceanographic models.

Year 3: Examine tracer signatures from circumpolar ocean datasets to partition the amount of exported carbon from the Antarctic continent from groundwater sources. Examine how these groundwater carbon effluxes are distributed across the Antarctic Ocean across daily to centennial timescales. Begin to compile results into manuscripts for peer-reviewed publications, and present outcomes at a national conference.

Year 4: Write up and submit thesis. Finalise manuscripts. Present seminal results at an international conference.

Developing capacity that strengthens the school

This interdisciplinary PhD project sits at the interface of glaciology, geology, and oceanography, and therefore finds a natural home with both the School of Geography and Sustainable Development (GSD) and the School of Earth and Environmental Sciences (EES). By re-examining the global and regional water and carbon cycle, the project uniquely addresses the University theme of Evolution, Behaviour, and Environment.

The interdisciplinary nature of this research – at the boundary of bedrock geology, glaciology, oceanography, and biogeochemistry – makes it highly relevant to the broad focus, community, and strategy in both the Schools of GSD and EES. The work will pose stimulating questions and provide novel insight into processes relevant to a wide range of timescales, from ice age dynamics to future climate. As such, it will be of interest to, and interface with, a broad range of glaciological, biogeochemical, geological, and environmental science researchers in both Schools.

In particular, the research naturally aligns with the GSD interests of the Global Environmental Change Research Group (ECRG), which also houses the St Andrews Glaciology Group (StAG) and a number of researchers internationally recognised for their work in understanding the global carbon cycle. The research also fits seamlessly with the EES interests of the Climate, Oceans, and Atmosphere @ St Andrews (COASt) research consortium, wherein a number of faculty, postdocs, and PhD students coalesce around the broad theme of climate, exploring the fundamental physical and biogeochemical dynamics on a range of timescales.

Anticipated supervision arrangements and supervision strengths

The PhD student will be supervised by T.J. Young (GSD) and Graeme MacGilchrist (EES). Though early in their respective academic careers, both are at the forefront of their respective fields, and together provide complementary perspectives that guarantee effective supervision of the project. As well as dedicated supervisory meetings, the student will also be included in established biweekly meetings with the StAG and COASt research consortia, where the student will find natural synergies with fellow students, researchers, and faculty members working on similar glaciological and oceanographical research.

T.J. Young (Lecturer in Glaciology) has expert insight into the hydrological dynamics controlling large glaciers and ice sheets. T.J. will supervise the ice sheet-groundwater modelling component of the PhD, and work with the student towards developing a coupled glacier-groundwater model that maps groundwater export from the Antarctic ice sheet.

Graeme MacGilchrist (UKRI Future Leaders Fellow) is a leader in high-latitude oceanographic processes and how these influence the transport and storage of climate relevant tracers such as heat and carbon. Graeme will supervise the oceanographic component of the PhD, through leveraging ocean models to understand how groundwater modulates regional circulation, and how this reframes the circulation and and carbon cycle of the larger Southern Ocean.

Confirmation that the application has the support of School leadership

This application has explicit support of the Directors of Postgraduate Studies from both the Schools of GSD (Dr. Christopher Schulz) and EES (Dr. Eva Stueeken), who will separately provide letters of support following the submission of this application.

Further reading

Chu W. (2022) Groundwater under Antarctica goes deep. *Science* **376**,577-578. doi: 10.1126/science.abo1266

Gustafson CD *et al.* (2022) A dynamic saline groundwater system mapped beneath an Antarctic ice stream. *Science* **376**,640-644. doi: 10.1126/science.abm3301

Liljedahl LC *et al*. (2021) Rapid and sensitive response of Greenland's groundwater system to ice sheet change. Nature Geoscience **14**:751-755. doi: 10.1038/s41561-021-00813-1

Siegert MJ *et al*. (2018) Antarctic subglacial groundwater: a concept paper on its measurement and potential influence on ice flow. Geological Society London, Special Publications 461:197-213. doi: 10.1144/SP461.8