Investigating Feedbacks between Landscape Evolution and Ice-Sheet Dynamics (Ref IAP-17-46)

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In partnership with Newcastle University, School of Geography, Politics and Sociology

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Key Words

Overview

Ice sheets shape their own future by altering the topography beneath them. Over multiple glacial cycles the flow of ice preferentially erodes giant glacial troughs, up to 100km wide, and millions of tons of sediment are transported from the continent to the ocean. This redistribution of material not only directly reshapes the land beneath an ice sheet, but it also triggers a transient isostatic response that continues for tens of thousands of years. Continual re-shaping of the land will therefore alter the behaviour of the overlying ice sheet, but such feedbacks are not currently incorporated into numerical models of long-term ice sheet evolution.

The most important boundary conditions controlling ice sheet dynamics are the shape of the underlying topography, the nature of the ice-bed interface (e.g. sediment or bedrock) and, in the case of a marine-grounded ice sheet such as Antarctica, the depth of the bed in relation to the sea surface. These properties evolve significantly over multiple glacial cycles, potentially altering the large-scale dynamics and maximum extent of the ice sheet as well as its sensitivity to changes in climatic forcing.

Palaeo-topographic reconstructions of Antarctica have made simple assumptions about the evolution of the bed beneath the ice sheet over the last 34 million years [Wilson et al., 2012] and models have tested how ice sheets would grow on such topographies [Figure 1; Wilson et al., 2013]. However, these reconstructions do not reflect dynamic feedbacks between ice sheet processes and the evolving topography. Similarly, while the isostatic response to large-scale sediment redistribution has been quantified for a number of settings [Paxman et al., 2017], the long-term impact on ice-sheet configuration of gradually tilting the underlying landscape, and the potential implications for evolving patterns of erosion, has not been studied in a coupled framework. A third factor, which has so far received limited attention beyond the timescale of a single glacial cycle, is the impact of glacial isostatic adjustment on ice sheet dynamics [de Boer et al., 2017]. Deformation of the solid Earth in response to the redistribution of ice and ocean mass, and the accompanying spatially-variable change in sea level, has been shown to be part of a negative feedback loop that may limit the sensitivity of an ice sheet to climatic forcing [Gomez et al., 2010].

This project will make the first steps towards building a coupled numerical model that incorporates processes associated with erosion, isostasy, and ice dynamics. Building on previous work by the project supervisors [Jamieson et al. 2010; Whitehouse et al., 2012a,b], the student will seek to combine existing process-based models, with the ultimate goal of producing a model that accounts for feedbacks between landscape evolution and ice sheet dynamics. The model will be used to quantify the degree to which erosion and isostasy may impact on the long-term evolution of a glacial landscape, with particular focus on re-assessing the factors controlling the evolution of the Antarctic Ice Sheet over the past 34 million years.
Methodology

The focus of this project is on the development of a coupled numerical model that accounts for feedbacks between landscape evolution and ice sheet dynamics. The newly-developed model will be used to: [1] quantify feedbacks between glacial erosion and ice dynamics, and [2] quantify the impact of long-term sedimentary isostasy on ice dynamics. The results of model sensitivity studies will be used to [3] refine our understanding of the dominant processes controlling long-term ice-sheet evolution, with particular focus on Antarctica.

The student will draw on a range of existing information to tune the numerical model, including: contemporary estimates for glacial erosion rates in different geological settings; time-varying maps of offshore sediment deposition based on seismic data and marine sediment cores; and geological evidence for past rates of long-term landscape evolution.

The outcomes and impacts of this project will be: (i) development of the first numerical model that considers feedbacks between glacial erosion, isostasy, and ice dynamics; (ii) quantification of the effect of having previously neglected such feedbacks in earlier modelling studies; and (iii) a potential step-change in our understanding of the dominant processes driving long-term evolution of the Antarctic Ice sheet. Incomplete understanding of such processes is one of the main sources of uncertainty associated with current predictions of future sea-level change.

Timeline

**Year 1:** develop an understanding of glacial erosion, and sedimentary/glacial isostasy; training in numerical modelling and familiarisation with existing models; use of offline coupled modelling techniques to quantify the potential impact of erosion and isostasy on ice dynamics.

**Year 2:** compile geological data sets that will be used to test and tune the numerical models; use these data sets to tune the individual process-based models (e.g. replication of realistic rates of glacial erosion); progress towards development of a fully-coupled model (two-way feedbacks); develop presentation skills by attending UK-based glaciological conference.

**Year 3:** testing of fully-coupled model; carry out sensitivity experiments to quantify the impact of including new feedbacks in numerical models of landscape evolution and ice sheet dynamics; draft manuscripts for publication; present outcomes at international conference; draft thesis.

**Year 4 (six months only):** Complete and submit thesis; finalise manuscripts for publication; attend international conferences.

Training & Skills

This project will provide cross-disciplinary scientific training in problem solving, data analysis and report writing. It will provide the student with high-level skills in: (a) glaciology and geomorphology; (b) geodynamics; and (c) numerical modelling.

The student will also benefit from broad skills training provided in-house at Durham (e.g. thesis and paper writing, presentation skills etc.), from a broad range of environmental science training provided within the IAPETUS Doctoral Training Partnership framework, and from attending the Karthaus summer school.

References & Further Reading


glacial erosion and normal faulting. Journal of Geophysical Research: Solid Earth, 122


**Further Information**

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