Ocean and Climate Change Institute
Final Report

The Influence of Basal Meltwater on the Time-Integrated Sliding Behavior of the Greenland Ice Sheet

Mark D. Behn, Department of Geology and Geophysics

What were the primary questions you were trying to address with this research?

It is now recognized that surface meltwater can be rapidly transported from the surface to the bed of thick (>1 km) ice sheets through conduits that are formed and sustained beneath supraglacial lakes. However, the influence of seasonal meltwater in modulating time-integrated ice-sheet flow remains poorly understood. The goal of this work was to develop numerical models that quantify the time-averaged (i.e., multi-year) response of an ice sheet to changes in the spatial and temporal distribution of meltwater at the bed and to test these models using data collected on the western margin of the Greenland Ice Sheet.

What have you discovered or learned that you didn't know before you started this work? What were the most unusual or unexpected results and opportunities in this investigation?

A surprising result of this study is how sensitive the ice sheet response is to melt water input as a function of the timing of melt generation. For example, in situations where melt water is transported to the bed by a lake drainage event early in the summer, the ice sheet will accelerate and remain sliding at anomalously fast velocities for several weeks. However a similar volume of melt water transported to the bed late in the summer will result in only a transient speed-up for a few hours. These differences reflect how efficiently melt water can be channelized and drained from the base of the ice sheet, and indicate that the basal hydrologic system evolves throughout the year.

What is the significance of your findings for others working in this field of inquiry and for the broader scientific community?

The numerical methods developed through this project can be used in a wide range of scientific disciplines. For example, flow of the Earth's deep mantle follows similar physical mass transport laws (albeit with different material properties) as the flow of ice in glaciers and ice sheets. We can therefore use the same numerical models developed in this project to simulate mantle convection beneath mid-ocean ridges and subduction zones as we use for ice sheets.

What is the significance of this research for society?

Currently roughly 50% of the Earth's population lives within 50 miles of the coast, and this percentage is predicted to rise during the next 20 years. However, current models of sea-level rise are hampered by our inability to predict the dynamic response (i.e., the effects of enhanced ice flow) of the Greenland and Antarctic Ice Sheets. The goal of the models designed in this project are to understand how enhanced surface melting and the rapid transport of this meltwater to the bed of ice sheets will effect their future sliding behavior and the flux of ice to the oceans.

What were the greatest challenges and difficulties?

A major challenge in developing numerical methods to study the behavior of ice sheets on decadal to centennial time-scales is that melt-water forcing at the bed (e.g., supraglacial lake drainage events, diurnal melting, and precipitation events) can occur on time-scales of hours to days. Moreover, melt water input can be highly variable in space as well as in time. Thus, we must construct numerical models that allow us to couple the system across these different time and spatial scales.

When and where was this investigation conducted? What were the key tools or instruments you used to conduct this research?

This project utilizes numerical models to simulate the annual to decadal behavior of ice sheets and glaciers. It is important to stress that while these models are not able to make exact predictions for future behavior, they allow us to constrain the key variables (e.g., rate of melt water input to the basal hydrologic system) that control ice sheet behavior. In this way, we can make broad predictions for what factors will be most important in influencing ice sheet stability in a warming climate.

Is this research part of a larger project or program?

While the primary goal of this project was to develop new numerical tools for simulating ice sheet behavior, I am simultaneously working with other WHOI scientists and Joint Program students to make field measurements on the western margin of the Greenland ice sheet. Specifically, we are measuring surface melting rates and concurrent ice sheet motions using GPS and seismic instruments. These data sets provide direct constraints on the numerical models developed through this project.

What are your next steps?

To date my modeling has focused on land-terminating ice sheet margins, however, many of the most rapid changes in ice flow in Greenland and Antarctic occur where the ice sheet terminates in the ocean. Future models will focus on these marine-terminating margins in order to understand the role of ice shelves in "buttressing" ice flow and regulating the flux of ice into the oceans.

Have you published findings or web pages related to this research? Please provide a citation, reprint, and web link (when available).

<u>Journal Articles:</u>

Joughin, I., S.B. Das, G.E. Flowers, **M.D. Behn**, R.B. Alley, M.A. King, B.E. Smith, J. Bamber, M.R. van den Broeke, J.H. van Angelen, Influence of supraglacial lakes and ice-sheet geometry on seasonal ice-flow variability, *Cryosphere*, (submitted and available for online comment, February 2013).

Conference Proceedings:

Stevens, L.A., **M.D. Behn**, S.B. Das, I. Joughin, and M.A. King, 2013, Constraining ice sheet visco-elastic response to supraglacial lake drainage events, PARCA, Washington DC, 22-23 January.

Das, S.B., **M.D. Behn**, and I.R. Joughin, 2011, Modes of supraglacial lake drainage and dynamic ice sheet response, Abstract C13C-01, presented at 2011 Fall Meeting, AGU, San Francisco, CA, 5–9 December.