Examining the response of marine-terminating glaciers to melt variability through modeling basal controls on flow in West Greenland

1 Introduction

Understanding and predicting the response of the Greenland Ice Sheet to climate change is one of today's foremost scientific questions. A particular challenge exists in distinguishing controls on the behavior of fast-flowing tidewater outlet glaciers. Many of these fast outlet glaciers, responsible for half of the Greenland Ice Sheet's contribution to sea level rise, are currently undergoing dramatic retreat.[1] While the role of calving and ice/ocean interactions has been examined, the impact of hydrologic and geologic controls such as surface water discharge and properties of basal sediment is less well studied. Improving the understanding of the feedbacks between these controls is integral to the development of more accurate models of Greenland's response to a warming climate.

Basal sediment is known to regulate ice flow in Antarctica, but a paucity of research exists regarding basal processes in Greenland. Recent groundbreaking research conducted at Russell Glacier, a land-terminating glacier in west Greenland, demonstrates that changes in sediment strength related to seasonal distribution of water to the bed are a significant control on flow for soft-bedded glaciers.[2] Decreases in sediment strength are related to the frequency of high water discharge events due to feedbacks between sediment properties and hydrology. Surface water melt and/or subglacial lake discharge events raise water levels at the bed, increasing sediment porosity and thus causing decreased basal resistance and faster flow. As flow increases, thinning of the glacier eventually causes reduced basal meltwater production, initiating till compaction and damping flow.

These feedbacks suggest that outlet glaciers overlying soft sediment may be more sensitive to increasing melt if climate change causes more variability in discharge. Significantly, models of Greenland's contribution to sea level rise do not incorporate basal sediment's control on flow.[3] Without an understanding of basal controls on flow for marine-terminating glaciers, the largest contributors to sea level rise, estimates of sea level rise are uncertain. I propose to numerically model marine-terminating Store Gletscher in West Greenland, with the goal of developing a more complete understanding of hydrologic and geologic controls on the fast flow of a large outlet glacier. By changing the hydrologic inputs and evaluating the model's response to increasing and varied surface melt and subglacial lake drainage, I will assess the basal controls on Store Gletscher's flow and thus its sensitivity to a warming climate.

2 Research Questions

1. How does basal lubrication modulate flow for marine-terminating outlet glaciers?
2. How will increasing meltwater production impact lubrication at the bed?

3 Methods

For the primary model of ice flow, I plan to utilize a 3-D higher-order ice sheet model known as the Community Ice Sheet Model (CISM).[4] This model solves for ice thickness using the continuity equation and maintains conservation of momentum through first-order approximations of the Stokes equations for ice flow. The advective-diffusive heat equation for ice sheets is used to control conversation of energy. I will determine boundary conditions at Store Gletscher through consulting past research at Store Gletscher[5] as well as examining previous applications of the CISM. This model has been utilized to assess hydrologic controls and sedimentary processes in Antarctic Ice Streams and outlet glaciers in Greenland.[2,6,7] My research will involve coupling this general model to models of basal sediments and hydrology.

To incorporate the impact of basal processes, I will first test the model with a simple, laboratory parameterization of till yield stress. Using information gained from that experiment, I plan to develop a more complex model of basal processes. As sediment strength and porosity are both independently related to the sediment strength pressure, it is possible to solve for sediment strength as a function of porosity.[6] Changes in porosity throughout the sediment layer caused by water flow can be determined through utilizing both mass continuity and hydraulic pressure gradients. The excess pressure is thus calculated using the vertical pressure gradients in the sediment. This pressure is used to determine the force on the base of the glacier, allowing one to build a necessarily more complex model of sediment's impact on flow.[6]

Seasonal delivery of meltwater to the bed of the glacier has been shown to regulate flow, and modeling the evolution of flow over the ablation season will be a significant component of my research. After creating a model of basal and hydrologic processes, I plan to utilize a regional climate model to input hydrologic forcing and assess the model's utility. I will also be able to use various changes in runoff to assess the glacier's efficiency in water distribution and its response to increased water at the bed. Through conducting modeled experiments with varying hydrologic inputs, I hope to determine how surface meltwater currently influences flow and how the glacier will respond in the future to increased meltwater production. The results of these experiments should indicate the sensitivity of marine-terminating glaciers to changing climate conditions.

4 Broader Impacts

The goal of this project is to determine how increasing surface melt impacts the basal control on flow through modeled numerical experiments. Additionally, through changing inputs into the model and comparing the results to field observations, this research will also assess the stability of Store Gletscher and its sensitivity to varied hydrologic and climatic forcing. Current research on outlet glaciers in Greenland is largely focused on studying their response to climate change and thus their predicted contribution to sea level rise. Understanding the link between hydrologic forcing, basal processes and flow will allow these controls to be included in future models of sea level rise. Increasing the accuracy of models of sea level rise is vitally important for not only glaciology and geoscience research, but also for policy and industry worldwide. By creating an applicable model of the basal control on flow in Greenland, this project could have significant implications for future study of Greenland outlet glaciers and their response to climate change.

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