1 Introduction

Many tidewater glaciers undergo periods of slow advance followed by rapid retreat.[1] A proposed mechanism for this behavior is as follows: subglacial weathering produces copious sediment, which is transported by glaciofluvial processes to the terminus, where it deposits to form a shoal. The glacier advances onto the shoal, while simultaneously eroding the overridden sediment. This produces an overdeepening and a reverse bed slope. Eventually the mass balance is insufficient to maintain glacier thickness, and the tidewater glacier comes afloat and rapidly disintegrates back to a stable position, where the process begins again. This is known as the *tidewater glacier cycle*. This cycle is convolved with climate, and can make analysis of climate induced changes in glacier behavior complex.

Taku glacier, an outlet of the Juneau icefield in southeast Alaska is exhibiting this process: the terminus is advancing over a submarine sediment shoal while rapidly excavating overridden sediment upglacier.[2] Taku glacier and the Juneau ice field are also among the best documented glacial systems in North America. This combination of dynamic behavior and dense observations provides an unprecedented opportunity to model the tidewater glacier cycle and to analyze its importance in the context of interpreting climate change. The following are three specific hypotheses that I will address through modelling and field observation:

H1: Glacial limit cycles. Periodic behavior in marine glacial terminus position can be initiated and sustained with a constant input from the climate. The tidewater glacier cycle can be sustained by the interaction between subglacial geomorphology and ice dynamics. This is known as a limit cycle.

H2: Robustness to climate variability. The tidewater glacier cycle is a stable limit cycle: slow external forcing, such as changes in surface mass balance and external sedimentation change the rate and magnitude of advance and retreat phases, but neither qualitatively nor permanently alter the structure of the cycle.

H3: Sensitivity to till properties. Nonlinearity in till rheology and its relationship with basal sliding play a major role in determining the timescale of the advance stage of the tidewater glacier cycle, but does not have a strong impact on retreat rates once retreat has been initiated.

2 Model development and application

2.1 Simplified experiments

I will address **H1** by modelling a hypothetical glacier flowline with an idealized geometry and surface mass balance similar to MISMIP Exp. 3.[3] This configuration is advantageous because its grounding line behavior is already well understood in the absence of sedimentation. Ice dynamics will be simulated with the glacier model VarGlaS[4] coupled with a semi-empirical sedimentation model similar to the one proposed by Oerlemans et al.[5] I will address **H2** by examining the sensitivity of the cycle to perturbations in surface mass balance, sedimentation rate, erosion rate, and basal friction parameters.

[1] Meier and Post, "Fast tidewater glaciers". [2] Motyka et al., "Rapid erosion of soft sediments by tidewater glacier advance: Taku Glacier, Alaska, USA". [3] Pattyn et al., "Results of the Marine Ice Sheet Model Intercomparison Project, MISMIP". [4] Brinkerhoff and Johnson, "Data assimilation and prognostic whole ice sheet modelling with VarGlaS". [5] Oerlemans and Nick, "Modelling the advance-retreat cycle of a tidewater glacier with simple sediment dynamics".

2.2 Application to Taku glacier

I will perform similar experiments to those outlined in Sec. 2.1, but using data from Taku glacier. Taku glacier is unique in North America in that it possesses a >50 year surface mass balance record,[6] as well as sufficient surface velocity and thickness data to compute basal topography using mass conservation methods.[7] The subglacial erosion rate will be calibrated using measurements from Motyka.[8] I expect that the model behavior will be sensitive to basal sliding rates, which generally vary due to unobserved basal conditions, e.g. bedrock or till bed, subglacial water pressure, bedrock roughness. To address this, basal shear stresses will be inferred from a combination of inversion on remotely sensed surface velocities[9], as well as directly observed sliding velocities over subglacial till (See Sec. 3).

3 Field observations

I will accompany an NSF funded field team from UAF to the Taku glacier during the Summer 2015 field season; this work is a component of an ongoing scientific campaign.[10] We will use a hot water drill to open several small boreholes to the bed near the glacier terminus. I will install three vertical arrays of inclinometers in order to measure englacial deformation, and combined with high precision surface velocity measurements, this will produce estimates of both basal shear stress and basal velocity.[11] Combined with measurements of subglacial water pressure, and material analyis of proglacial sediments, this will provide a robust estimate for a sliding law over till beds for this study site, and therefore a means to address **H3**.

4 Intellectual merit

This work contributes to the existing *corpus* of glaciological knowledge in a few principle ways. First, by understanding the time scales and principle driving mechanisms of natural glacier advance and retreat for the specific case of Taku glacier, we will be able to make inferences about similar behavior occurring in tidewater environments throughout the world. Second, this work will produce the technical means to simulate glacier-sediment interactions in other dynamic glacial systems (e.g. surging glaciers). Third, my study of the interaction between till mechanical processes and glacier sliding will contribute to the development of a well constrained sliding law for glaciers and ice sheets, which is one of the most important unrealized goals in glaciology, as it is necessary for convincing prognostic simulations.

5 Broader impacts

At present, any analysis of dynamic glacier behavior is inseparable from its implications regarding changes in climate and commensurate sea level rise, and cryosphere response remains one of the principle wild cards in projecting the human cost of climate change.[12] This work aims to reduce the uncertainty in sea level projections, both by deconvolving long term climate signals from the tidewater glacier cycle, and by providing additional observations towards constraining models of sliding velocity. Furthermore, the improved understanding of ice-sediment interactions provided by both field studies and modelling will provide an enhanced framework for predicting pro- and subglacial sedimentation in the context of ecology and landscape evolution.

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[6] Pelto, Kavanaugh, and McNeil, "Juneau Icefield Mass Balance Program 1946-2011". [7] Johnson and Brinkerhoff, "Application of physics based interpolation to cryospheric data (invited)". [8] Motyka et al., "Rapid erosion of soft sediments by tidewater glacier advance: Taku Glacier, Alaska, USA". [9] Fahnestock, "Landsat 8 Ice Flow". [10] Truffer et al., "Terminus dynamics at an advancing glacier: Taku Glacier, Alaska". [11] Raymond, "Flow in a transverse section of Athabasca Glacier, Alberta, Canada". [12] Stocker, Dahe, and Plattner, "Climate Change 2013: The Physical Science Basis".