Statement of Research and Teaching Interests

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Research

My broad interests lie in the fascinating and often complex array of processes governing the evolution of the climate system and the behavior of the Earth system more generally. I particularly enjoy looking at systems from a theoretical perspective, trying to tease out the key relationships between components, sometimes in a heuristic fashion, preferably from first principles, but always guided by observations and hypotheses. Ice sheets and glaciers are critical components of the climate system due to their ability to produce changes in climate and sea level on time scales ranging from sub-millennial to millions of years. Ice sheets and glaciers are also powerful geomorphic agents, reshaping landscapes on regional to continental scales. Further, ice sheets can have important geodynamic effects through isostasy and crustal flexure. My glaciological research focuses on the climatic and geomorphic aspects of the behavior of glaciers and ice sheets. In particular, my research thus far has focused on two problems: (i) assessing the ability of ice sheets to quickly respond to changes in climate, with implications for sea level; and (ii) determining the conditions under which ice sheets can produce large subglacial water reservoirs, a prerequisite for the sizable outburst flooding events seen in the geomorphic record. I next describe each problem briefly.

Sea level and buttressing: Presently the Greenland and Antarctic ice sheets have the potential to raise sea level by $\sim$70 meters if they were to completely melt; even a fraction of this amount of sea-level change would be catastrophic to coastal communities. Clearly, it is important to assess the susceptibility of the present ice sheets to melting in a warming world. Over the last 10+ years some glaciological models have suggested that these ice masses are essentially invulnerable to a warming climate, at least on time scales of interest to humans. It is these results that the Intergovernmental Panel of Climate Change (IPCC) used, in both 1995 and 2001, in downplaying the potential for ice sheets to produce notable changes in sea level. However, the models involved in these assessments neglected the physical processes governing the flow of ice streams and ice shelves, arguably the components of ice sheets most likely to respond quickly to oceanic or atmospheric warming. Recent observations have shown the folly of this neglect. For example, satellite observations showed a large (up to 8x) acceleration in glaciers flowing into the former Larsen B ice shelf, subsequent to its warming-induced breakup in 2002. Additional remote sensing revealed that Jacobshaven Isbrae, in Greenland, experienced a nearly two-fold increase in speed in response to increased sub-ice-shelf melting. Similarly, Pine Island Glacier, in West Antarctica, is experiencing extensive acceleration and thinning due to sub-ice-shelf melting. These recent and rapid responses point toward a strong sensitivity to a reduction in the buttressing provided by ice shelves. Clearly, a model which includes ice-stream/ice-shelf physics was needed. For the particular problem of assessing the sensitivity of stream/shelf systems to buttressing perturbations I developed a time-dependent, one-dimensional (in space) numerical model of stream/shelf momentum and mass-balance. My results show that, through the influence of longitudinal stresses, such systems can indeed be quite sensitive to a reduction in buttressing, and that this sensitivity is governed by only a few system-dependent parameters. This work was pubished in *Geophysical Research Letters*.

Outburst floods: Recent marine-geophysical evidence offshore of West Antarctica as well as along the northeast coast of North America led to the hypothesis that large outburst floods from overpressured subglacial lakes have had dramatic geomorphic, and perhaps climatic consequences during the last glaciation. A key component of this ”outburst flood” hypothesis is the trapping of subglacial water. One possible mechanism for such trapping is a reversal in subglacial hydraulic gradient through the presence of a reversal in the ice-air surface slope. To explore the feasibility of this mechanism, I used a modified version of the simple stream/shelf model described above to examine the conditions under which such surface-slope reversals would form. The results suggest that surface-slope reversals should be expected under a wide variety of reasonable scenarios, thus bolstering the outburst flood hypothesis. This work is in press in *Annals of Glaciology*.

The model I developed for the two problems outlined above is applicable to a wide variety of problems involving ice-stream/ice-shelf dynamics. In addition, it is computationally efficient, which allows for sensitivity studies involving a large number of separate experiments. As such, I plan to use it a great deal in further studies. For example, I am presently using this model, in addition to a two-dimensional (plan view) version, to explore how the buttressing influence of ice shelves decays with distance back from the ice front. I also plan to publish a description of the numerical scheme employed - a form of Petrov-Galerkin upwinding - in the mass-balance component of the model, as it appears to be an improvement on existing treatments in glaciology.

There are several other projects that I plan to work on in the near term, some still in the planning stages, others to be submitted to NSF in the near future. One of these projects, which is now fully funded by NSF, examines the influence of the ice-air surface topography on the evolution and stability of subglacial hydrologic regimes, with implications for the creation and stability of subglacial lakes; this study will use a suite of models of various complexity to improve our understanding of the physics behind outburst floods. As part of another project, soon to be submitted to NSF, I will explore the influence of oceanic tides on the flow of ice streams and shelves by developing and applying a viscoelastic force-balance model for ice.

My research interests go beyond glaciology. For example, the behavior of the full range of geophysical fluids holds a particular fascination for me. This includes a strong interest in coupling a dynamic cryospheric component model to computational models of the atmospheric and oceanic climate. I am also interested in the dynamics involved in sub-ice-shelf thermohaline circulation. In addition, I see the application of data-assimilation/inverse methods to formally meld geologic data and models as a key in accurately simulating Earth processes. Thus I seek to expand my theoretical efforts in these and other directions as part of an effort to foster a strong quantitative, hypothesis-driven research program involving undergraduate and graduate students, along with interdisciplinary collaborations within and outside of my resident institution.

Teaching

I have wanted to be an educator all my life. I enjoy sharing knowledge, but just as importantly, sharing strategies for learning, thereby giving students the tools to educate themselves beyond the classroom. My experiences as both a student and, more recently, an instructor, have given me a deep appreciation for the challenge of finding ways of helping a diverse array of students; clearly, there is no single way for all students to master a given subject, and thus my preference is to be as flexible and open-minded as possible. This applies to undergraduates in a general education course all the way up through senior graduate students in an advanced seminar course.

I've found that two of the biggest challenges facing a student in the earth sciences are educating their physical intuition and overcoming a near ubiquitous math-phobia. My favorite approach to improving physical intuition is to use as many real-world analogies as I can, prodding students to come up with their own analogies if possible. The issue of math-phobia is a more difficult hurdle; here, my favored approach is to keep the student(s) actively involved in the process of converting verbal concepts into mathematical forms and back again. In actively engaging students in both educating their intuition and developing quantitative forms of qualitative concepts, the students will gain confidence in their ability to use critical reasoning in problem solving.

Many students find it much easier to learn while sitting in front of a computer than from a live instructor. Therefore, when feasible, I would use web-based tutorials and exercises that require the active participation of the student. For example, to give students a sense of the aspect ratio and relief of the ocean floor I would include an exercise involving the manipulation of a 3-d map of ocean bathymetry with a mouse. I would similarly encourage the use of online data sources for term papers and group projects. Where appropriate in upper-level courses, I would use simple programing assignments, in addition to visualization packages, to help give students a more personal and immediate 'feel' for physical concepts and processes.

With my already broad teaching experience (outlined in my CV), as well as my interests and research expertise, I feel I could teach courses that would fall within the purview of several departments. However, my greatest strengths lie within the earth sciences, and thus the following are examples of courses I feel I could teach in a geoscience context:

Sample Earth Sciences Teaching Portfolio

General Education

- Gaia – The Earth System – An interdisciplinary introduction to the processes, interactions, and evolution of the Earth's biosphere, geosphere, and hydrosphere.
- Planet Earth – Nontechnical presentation of earth processes, materials, and landscape.
- Geology of National Parks – Introduction to geology, geological change, and environmental hazards, as seen in the National Parks

Undergraduate Major

- Physical Processes in Geosciences – An in-depth examination of various physical processes that operate within and at the surface of the earth
- Geology of Climate Change – Geologic evidence for climate change and mechanisms of change, especially from the Ice Age through the near future

Advanced Undergraduate or Graduate

- Quaternary Studies – Introduction to Quaternary climate change, emphasizing various proxy records and climate system dynamics
- Glaciology – Seminar using text, literature and student-driven discussion to look at glaciological observations and theories
- Geophysical Fluid Dynamcs – Introduction to the dynamics of geofluids in a broad sense, applying concepts from fluid dynamcis to phenomena within the atmosphere and oceans, the solid earth, porous media, and the cryosphere
- Mathematical Modeling in the Geosciences – The process of transforming a conceptual geoscience model into mathematical and numerical models is presented; students create and solve simple numerical models
- Advanced Mathematical Modeling in the Geosciences – A introduction to more advanced topics in analytic and numerical modeling, from scaling, linearization, and elementary perturbation analysis to the implementation of simple finite element treatments
- Inverse Methods in the Geosciences – A gentle introduction to the formal synthesis of data and model for parameter estimation and model validation