Project EARTH-16-RK1: Melting and water drainage from ice-stream margins: theory and computation

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Antarctica is blanketed with ice sheets that represent an enormous reservoir of water. The mass of this reservoirs is set by a balance between the accumulation of snow, on the one hand, and the flow of the ice into the sea, on the other. A change in this flow has the potential to cause a rapid rise in sea level, with catastrophic consequences for humans. How ice sheets will respond to the perturbations of a changing climate is a question of critical importance. Answers will require a deep understanding of the mechanics of ice sheets, and in particular of ice streams. These are the large 'rivers' of fast flowing ice, which are responsible for discharging much of Antartica's ice, but who's origin remains enigmatic.

Recent work indicates that viscous dissipation at the margins of ice streams can locally raise the temperature of an ice sheet to the melting point, and subsequently generate melt water. The detailed physics of this two-phase system remain largely unexplored: What is the rate and volumetric extent of melting? How rapidly does melt drain from the source region and what is the ambient porosity and permeability of that region? How does the presence of melt-water feed back on ice dynamics via the ice rheology? These are just a few of the open questions. The purpose of this project is to develop and extend theory based on fundamental conservation principals (mass, momentum, and energy) for an ice/water system in terms of partial differential equations. Furthermore, it is to obtain solutions to these equations at various levels of complexity, using analytical and numerical methods. Finally, it is to generate physical predictions based on simple model assumptions and compare those predictions with data and with eachother.

There has been relatively little work on two-phase models of ice sheets, but the present is an opportune time to develop them. Recent advances in two-phase modelling of coupled magma/mantle dynamics have introduced methods from metallurgy into geodynamic calculations to impose conservation of energy in a multi-phase system. These methods can be applied in glaciology, and indeed an early effort to this end has been published. The project supervisors can draw on expertise in both magma/mantle and ice-sheet dynamics to guide development of theory appropriate for this project.

The student will extend the typical treatment of an ice sheet (incompressible Stokes equation for viscous flow) to incorporate the mechanics of a low-viscosity phase (water) in the pores between ice crystals. The thermodynamics of this system will be constrained via the Enthalpy Method, or a similar technique. The resulting PDEs will be treated with a range of tools, from scaling analysis to full numerical solutions, in geometries and domains from highly simplified to moderately detailed.

The successful applicant, whose first degree might be in earth sciences, engineering, physics or mathematics, will have a good background in maths and physics and an interest in computer modeling of physical phenomena.

References

Kyrke-Smith T., R.F. Katz, and A.C. Fowler (2013) Subglacial hydrology and the formation of ice streams. *Proceedings of the Royal Society A*. doi: 10.1098/rspa.2013.0494.

Schoof, C. (2012) Thermally driven migration of ice-stream shear margins, *Journal of Fluid Mechanics*, http://journals.cambridge.org/abstract_S0022112012004387

Hindmarsh, R.C.A. (2009) Consistent generation of ice-streams via thermo-viscous instabilities modulated by membrane stresses, *Geophysical Research Letters*, http://dx.doi.org/10.1029/2008GL036877