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Ice sheet dynamics with temperature-dependent sliding

Elisa Mantelli (1) and Christian Schoof (2)

(1) Stanford University, Geophysics, Stanford, United States (emantell@stanford.edu), (2) University of British Columbia, Earth, Ocean and Atmospheric Sciences, Vancouver, Canada

Alongside bed topography, thermo-mechanical feedbacks are considered the main driver of patterning in the velocity field of ice sheets. Faster ice flow dissipates more heat, and in turn higher temperatures can change the material properties of the ice (or ice-bed contact) in such a way as to lead to even faster flow. These feedbacks come in two basic forms: either ice becomes less viscous at higher temperatures, or sliding between ice and bed is temperature-dependent. In this study we focus on the latter, with the goal to understand ice sheet dynamics mediated by this feedback.

A number of basal boundary conditions meant to incorporate temperature-dependent sliding have been proposed, but the mathematical and dynamical properties of the resulting ice flow models are still largely unexplored. To fill this gap, we start by analyzing the limiting case of sliding switching on abruptly where bed temperature reaches the melting point. Our results illustrate that this set-up localizes the acceleration from no to finite basal sliding over a distance comparable with the ice thickness, and that such localization leads necessarily to refreezing of the bed. We conclude that, in order to avoid refreezing, the length of the transition region has to scale with the ice sheet scale, which is possible only if significant sliding occurs below the melting point.

Physically, sliding below the melting point is possible as a result of regelation and premelting, which can be accounted for with a temperature-dependent sliding law. In practice, in this set-up cold- and temperate-based portions of the ice sheet are intervened by a region of subtemperate sliding, where basal temperature is close to the melting point and the bed remains approximately in thermal balance. Coupling a temperature-dependent sliding law to suitable thermo-mechanical models of ice flow allows us to show that (i) an extended region of subtemperate sliding prevents refreezing of the bed; (ii) the subtemperate region is dynamically important. In fact, this region is unstable to a broad band of wavelengths ranging from the ice sheet to the ice thickness scale, with maximum growth at the ice thickness scale. We conclude discussing the physics of this instability, which relies on a thermal runaway feedback, as well as its implications with respect to the large scale thermal structure of the ice sheet.