Ice stream stick-slip, sticky spots and rate-and-state friction

J. N. Bassis
Department of Atmospheric, Oceanic and Space Sciences, University of Michigan

The Whillans ice plain is highly unusual in that it is nearly stagnant during most of the day, but lurches forward twice daily by nearly half a meter during short-lived stick-slip events. These highly repeatable sliding events are choreographed to the rhythmic waxing and waning of the ocean tides. This behavior presents an interesting, but significant challenge to ice sheet models for two reasons. First, the stick-slip of the WIS requires elastic deformation of the ice with viscous flow of the ice only playing a secondary role. Second, the stick-slip behavior of the WIS is inconsistent with the array of sliding laws conventionally used in ice sheet models ? stick-slip requires resistance from friction that decreases with increasing velocity. Most sliding laws, in contrast, are velocity strengthening. These inconsistencies hint that simulations of ice sheet evolution may require models that not only include viscoelasticity, but are also capable of resolving individual stick-slip events. In this study, I use an elastic slider block model to show that rate-and-state friction laws, analogous to those used in earthquake studies, are consistent with stick-slip and tidally modulated ice stream flow. In this model stick-slip corresponds to slight velocity weakening, roughly consistent with rock-on-rock contact as would be the case if basal debris entrained within the ice is rubbing again exposed bedrock. Tidal modulation, in contrast, is consistent with slight velocity strengthening consistent with laboratory experiments in which sliding occurs through till deformation. Both velocity strengthening and velocity weakening sliding laws can be tuned to mimic more conventional sliding laws (and vice versa), but the distinction between velocity weakening and strengthening is crucial when examining the response of individual ice streams to perturbations. While these results remain speculative, it suggests that basal friction does not remain constant in time and understanding how friction evolves over time is likely to be both critical and difficult to predict.