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Changes to glacier friction law due to solid friction

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Theoretical laws for glacier friction over hard bedrocks rely on several assumptions. One fundamental assumption is that perfect sliding (no resistance to slip) occurs at the local scale between ice and bedrock, in which case friction only occurs at a mesoscale from ice flowing past bed irregularities - here called viscous friction. This assumption is however challenged by the numerous observations that glaciers carry debris at their basal layers, which can exert frictional resistance locally through solid-type friction between debris and rock. This is to be translated at a mesoscale as an additive frictional term to the law.
We study how the action of solid friction modifies the overall glacier basal friction by applying a simple effective-pressure dependant Coulomb friction law into a steady-state finite element model of a glacier over sinusoidal bedrock. We find that the viscous drag reaches the same maximum value regardless of whether there is local solid friction or not. However, we find that in the no-cavitation regime (low water pressures) the deformation-slip ratio near the bed is enhanced when solid friction occurs, although total slip is lower. As a result, the sliding parameter - ratio between viscous drag and slip - is no longer constant, as opposed to expected in a pure-sliding scenario. For high water pressures, the influence of solid friction becomes smaller and the law tends to the pure-sliding case. We propose a simple update to pure-sliding derived laws (Weertman, 1957; Fowler, 1981; Schoof, 2005; Gagliardini et al., 2007) to take into account this effect.

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