Geophysical Research Abstracts
Vol. 20, EGU2018-9259, 2018
EGU General Assembly 2018

Validating glacier sliding theories from observations at a natural scale

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In many glaciated environments, glacier dynamics is primarily set by basal sliding, which operates through frictional processes at the ice-bedrock interface. Our poor knowledge on the specifics of these frictional processes, along with their relative contribution to the overall basal sliding, causes large uncertainties in the form of the friction law to be used in large scale glacier and ice sheet models, and thus in predictions of ice-sheets contribution to sea level rise under a rapidly warming climate [Brondex et al., 2017, Ritz 2015].

Here we present an observational framework that, we believe for the first time at a natural scale, enables us to test, validate and constrain basal sliding theories for glaciers over a hard bed. We analyze a unique dataset on the Argentiere Glacier (Mont Blanc area, French Alps), which consists of three decades of in-situ basal sliding measurements made from a wheel placed sub-glacially [Vincent and Moreau, 2016]. We reconstruct an observed friction law from these measurements by evaluating changes in basal sliding velocities in response to changes in basal shear stress, induced thanks to significant glacier thinning over the investigated period. In striking agreement with existing theories, we find that sliding is set by two main frictional regimes. One regime is of Weertman's type, is observed at low stresses, and is characterized by a constant scaling exponent consistent with pressure-regelation and enhanced creep both controlling sliding. Another regime is of Lliboutry's type, is observed at higher stresses, and is characterized by a scaling exponent that increases with shear stress, consistent with increasing cavitation.

Besides providing unique constraints on the various parameters accounted for in existing theories, these observational findings also shed new light on glacier dynamics at seasonal to multi-decadal timescales. We observe that apparent basal shear stresses, defined as the ratio between shear stress and effective normal stress, often reaches a maximum set by the Iken's bound, after which plastic deformation and eventually shear weakening is expected. However, somewhat surprisingly, whenever the apparent shear stress reaches the Iken bound, there exists a stabilization mechanism that then limits sliding velocity to a single value. We suggest that this stabilization mechanism may either be due to a global glacier control, or to a transient feedback between changes in cavity volume and water pressure. Further work combining modelling and observations is needed to formulate and discriminate these effects.