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Assessing sliding relations for glacier slip over realistic bed topography

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Accuracy of prognostic ice-sheet models sensitively depend on the degree to which processes related to boundary conditions can be represented. In particular, the extent to which ice slides against and interacts with its substrate highly affects large-scale dynamics of ice sheets and glaciers. A process-based understanding of how basal drag and slip are related to conditions at the ice-bed interface, such as local bed topography, debris and subglacial hydrology, is therefore necessary to constrain ice-sheet response to a changing climate and associated sea-level rise.

We use a numerical model to simulate ice flow over a set of bed topographies of diverse morphological character; each model topography is the result of statistical analysis of a high-resolution digital elevation model of a glacier forefield, surveyed using ground-based LiDAR or drone-based photogrammetry. Allowing for ice-bed separation and water-filled cavities to form, we investigate the range of slip behavior by for each topography relating basal drag to slip velocity and water pressure and how this relation is affected by debris at the ice-bed interface.

Our results for realistic hard beds illustrate that there is an upper bound on the drag supported locally; this is in accordance with previous studies of hard-bedded slip over idealized two-dimensional topographies. The magnitude of this bound depends on the character of the bed, but is for the cases investigated only a fraction of the theoretical maximum and lower than values used in numerical ice-sheet models. However, the range of sliding velocities over which basal drag increases is for the considered topographies comparable to physically reasonable slip velocities, implying that substantial cavitation at the bed does not necessarily preclude a locally rate-strengthening slip relation. The presence of debris at the ice-bed interface influences the magnitude of the upper bound on the basal drag, broadening the range over which heuristic, rate-strengthening sliding relations commonly used in glacier-flow models can apply.

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