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Estimation of basal shear stresses from now ice-free LIA glacier forefields in the Swiss Alps

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In most cases, assessing the impacts of climatic changes on glaciers requires knowledge about the ice thickness distribution. Miscellaneous methodological approaches with different degrees of sophistication have been applied to model glacier thickness so far. However, all of them include significant uncertainty.
By applying a parameterization scheme for ice thickness determination relying on assumptions about basal shear stress by Haeberli and Hoelzle (1995) to now ice-free glacier forefields in the Swiss Alps, basal shear stress values can be calculated based on a fast and robust experimental approach. In a GIS, the combination of recent (1973) and Little Ice Age (LIA) maximum (around 1850) glacier outlines, central flowlines, a recent Digital Elevation Model (DEM) and a DEM of glacier surface topography for the LIA maximum allows extracting local ice thickness over the forefield of individual glaciers. Subsequently, basal shear stress is calculated via the rheological assumption of perfect-plasticity relating ice thickness and surface slope to shear stress. The need of only very few input data commonly stored in glacier inventories permits an application to a large number of glaciers.
Basal shear stresses are first calculated for subsamples of glaciers belonging to two test sites where the LIA maximum glacier surface is modeled with DEMs derived from accurate topographic maps for the mid 19th century. Neglecting outliers, the average resulting mean basal shear stress is around 80 kPa for the Bernina region (range 25-100 kPa) and 120 kPa (range 50-150 kPa) for the Aletsch region. For the entire Swiss Alps it is 100 kPa (range 40-175 kPa). Because complete LIA glacier surface elevation information is lacking there, a DEM is first created from reconstructed height of LIA lateral moraines and trimlines by using a simple GIS-based tool.
A sensitivity analysis of the input parameters reveals that the performance of the developed approach primarily depends on the accuracy of the ice thickness determination and thus on the accuracy of the LIA DEMs used. Good results are expected for LIA valley or mountain glaciers with ice thicknesses larger than 100 m at the position of their terminus in 1973. Calculated shear stresses are representative in terms of average values over 20 to 40% of the total glacier length in 1850.
Shear stresses strongly vary with glacier size, topographic conditions and climate. This study confirmed that reasonable values for mean basal shear stress of mountain glaciers can be estimated from an empirical and non-linear relation using the vertical extent as a proxy for mass turnover. The now available database could be used to independently test the plausibility of approaches applying simple flow models.