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Response of surface topography to basal variability along glacier flowlines

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Predicting the amplitude and distribution of surface topographic undulations on ice sheets and glaciers is useful because of their influence on surface mass and energy balance, atmospheric boundary-layer processes and supraglacial meltwater routing. We develop an approximate method of calculating the steady-state surface elevation response due to spatial perturbations in basal topography and slipperiness, on two-dimensional ice flow sections whose glaciological conditions (ice thickness, surface slope, basal slip ratio) vary along flow. Our main result is an integral transform describing spatially-nonuniform transfer of basal variability to the surface. It employs previously-published Fourier transfer functions derived through perturbing plane-slab Stokes flow (i.e. Gudmundsson, 2003), but circumvents the need to window the spatial domain to derive the local response. We used the integral transform to clarify the relationship between the wavelet transforms of the bed elevation profile and predicted surface undulations. We tested the transform on both a valley glacier and an ice sheet—on (1) the central flowline of Columbia Glacier in Alaska and (2) a flowline on the Greenland Ice Sheet ending on Nordenskiöld Glacier on the west coast. These applications show that the method can simulate the mesoscale surface topography ($0.1 \lesssim \lambda/H \lesssim 10$) on these flowlines qualitatively well, and that the basal slipperiness transfer there is much weaker than basal topography transfer over these wavelengths. Theoretical and practical limitations of the method, as well as its future extensions, are discussed.