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Dynamics and internal structure of an Alaskan debris-covered glacier from repeat airborne photogrammetry and surface geophysics

John Holt (1), Joseph Levy (1), Eric Petersen (1), Chris Larsen (2), and Mark Fahnestock (2)
(1) Institute for Geophysics, Jackson School of Geosciences, University of Texas, Austin, TX, United States (jack@ig.utexas.edu), (2) Geophysical Institute, University of Alaska, Fairbanks, AK, United States

Debris-covered glaciers and rock glaciers encompass a range of compositions and activity, and can be useful paleoclimate indicators. They also respond differently to ongoing climate change than glaciers without a protective cover. Their flow dynamics are not well understood, and their unique surface morphologies, including lobate fronts and arcuate ridges, likely result from viscous flow influenced by a combination of composition, structure, and climatic factors. However, basic connections between flow kinematics and surface morphology have not yet been established, limiting our ability to understand these features. In order to begin to address this problem we have undertaken airborne and surface studies of multiple debris-covered glaciers in Alaska and the western U.S.

Sourdough Rock Glacier in the St. Elias Mountains, Alaska, is completely debris-covered and exhibits numerous transverse compressional ridges. Its trunk also exhibits highly regular bumps and swales with a wavelength of $\sim$175 m and amplitudes up to 12 m. In the middle trunk, lineations (boulder trains and furrows) bend around a point roughly 200m from the eastern edge.

We acquired five high-resolution airborne surveys of Sourdough Rock Glacier between late 2013 and late 2015 using lidar and photogrammetry to assess annual and seasonal change at the sub-meter level. Differencing the DTMs provides vertical change while feature tracking in orthophotos provide horizontal velocities that indicate meters of annual motion. The flow field is highly correlated with surface features; in particular, compressional ridges in the lower lobe. Stranded, formerly active lobes are also apparent.

Surface geophysical studies were undertaken to constrain internal structure and composition using a combination of ground-penetrating radar (GPR) at 50 and 100 MHz in six transects, and time-domain electromagnetic (TDEM) measurements at 47 locations, primarily in an along-flow transect and two cross-flow transects. We infer from the GPR and TDEM data that Sourdough Rock Glacier is 40-50 m thick and consists of a core of relatively pure glacier ice preserved under a 2.5-3 m thick debris mantle.

In conclusion, Sourdough is actively flowing, with surface velocities that correlate with surface slope and thickness. A bedrock restriction is inferred from bending flow lines, low surface velocities, and localized thinning of the ice. This comprehensive suite of observations provides the potential to model ice flow and to ultimately link details of the surface morphology to accumulation and rheology through flow kinematics and internal structure.