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Insights into ice shelf buttressing and ice rheology on Rutford Ice Stream, West Antarctica, from synoptic-scale observations of tidally driven ice flow variations

Brent Minchew (1,2), Mark Simons (1), Bryan Riel (1), Pietro Millio (3,4)

(1) Seismological Laboratory, California Institute of Technology, Pasadena, CA 91125, (2) British Antarctic Survey, High Cross Madingley Road CAMBRIDGE CB3 0ET, (3) School of Engineering, University of Basilicata, Potenza, Italy, (4) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91125

Synoptic-scale observations of the response of ice streams to well-constrained forcing functions provide unique insights into ice stream dynamics and the underlying mechanics of glacier flow. Rutford Ice Stream, West Antarctica, is one of the few recognized ice streams with strong, observed, periodic ice-flow variability (e.g., Gudmundsson, 2006; Murray et al., 2007); numerous in situ observations of the subglacial environment (e.g., Smith et al., 2015); and extensive modeling efforts focused on understanding the mechanisms that drive the observed variations in glacier flow (e.g. Thompson et al., 2014; Rosier et al., 2014; 2015). Despite these efforts, the processes underlying the ∼20% modulation in horizontal ice flow at Msf (14.77-day) periods—which corresponds to the beat frequency of the lunar and solar semi-diurnal ocean tides—remain a mystery. To help resolve the salient processes, we contribute a first-of-its-kind observational dataset that provides ice-stream-scale measurements of 3D secular and time-varying ice flow on Rutford with ∼40-m spatial resolution. These data were inferred from 9 months of continuous synthetic aperture radar observations collected with the COSMO-SkyMed 4-satellite constellation from multiple satellite viewing geometries. The resulting velocity fields provide constraints on ice flow in all three spatial dimensions and in time, making them true 4D surface velocity fields. The time-varying velocity field components elucidate the spatial characteristics of the response of ice flow on Rutford to ocean tidal forcing and agree with collocated GPS measurements. We show that the response of horizontal ice flow to ocean tidal forcing is most pronounced over the ice shelf and subsequently propagates through the grounded ice stream at ∼29 km/day, decaying quasi-linearly with distance over ∼85 km upstream of the grounding zone. We observe multiple regions over the ice shelf whose motion is consistent with subglacial pinning points and that provide a potential explanation for observed variations in horizontal ice flow. Cross-flow profiles of horizontal ice flow taken upstream of the grounding zone indicate that ice in the shear margins is significantly weakened relative to the central ice stream trunk, allowing for the possibility that buttressing stresses from the ice shelf are transmitted upstream through the ice column (Thompson et al., 2014).