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Basal Seismicity Forced by Surface-Water Supply on a Stepped-Bed Glacier: Saskatchewan Glacier, Alberta, Canada

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Parameterization of glacier sliding-laws remains a large source of uncertainty in modeling glacier and ice-sheet flow, requiring validation with experimental and observational data. In the case of ice flowing over a till-free, step-shaped bed, theory predicts bed resistance is independent of glacier sliding speed – a “rate neutral” sliding-law (e.g., Iken, 1981). However, experimental simulation of this system resulted in a notable anti-correlation between sliding speeds and bed resistance – a “rate weakening” sliding-law – that may give rise to basal seismicity (Zoet & Iverson, 2016). To investigate this discrepancy, we conducted a seismic field campaign on Saskatchewan Glacier, which is thought to have a stepped bed like those observed in adjacent glacier forefields. The campaign included a dense, 32 seismometer deployment during the middle of the 2019 melt season, complemented by continuous meteorologic, hydrologic, and GPS observations.

Visual and automated characterization of collected seismic data indicate abundant seismicity near the glacier’s bed. Basal seismicity clusters down-flow from an active moulin and a crevassed region likely connected to the bed. Rates of basal seismicity show a strong diurnal signal, consistently occurring 0.5-4 hours after peak surface melting and subglacial discharge, and continuous GPS data indicate temporary ice-flow acceleration during at least two diurnal seismic cycles. Spikes in seismic rate are also observed during most rain events with shorter response-times than diurnal cycles. The diurnal basal seismic cycle was interrupted by two periods of relative quiescence. The first lasted six days, initiating as mean air temperatures and peak daily subglacial discharge rose, and concluding after mean air temperatures and peak discharge declined. The second lasted one day following an abrupt drop in air temperature and was concurrent with reduced subglacial discharge.

We postulate that rapid surface water delivery to the bed strongly influences basal water pressure near delivery points, triggering bursts of seismicity on parts of Saskatchewan Glacier’s bed. Elevated rates of basal seismicity follow peak hydrologic flux through the subglacial drainage system, indicating that stick-slip motion likely occurs as water pressures fall from a transient. Some seismicity is accompanied by temporary acceleration of the glacier, consistent with results from Zoet & Iverson (2016). The six day period of relative quiescence may reflect reorganization of the subglacial hydrologic system into a more efficient drainage network in seismogenic regions, thus damping water pressure transients. Conversely, the one day quiescent period was likely the result of limited surface-water supply. We propose that temporary transitions from stable to stick-slip sliding occurred when basal water pressure exceed a critical threshold on parts of the bed, as modulated by surface-water supply and subglacial drainage efficiency.

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