Control of ice stream stick-slip dynamics by frictional healing

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Understanding the dynamics of Whillans ice stream is essential for predicting the future stability of the West Antarctic ice sheet, particularly in light of its recent slow-down. However, the observation that motion in the downstream portion is dominated by two stick-slip events per day has revealed a new complexity in the flow of this ice stream. A comprehensive model of stick-slip motion that can successfully explain the significant variability in slip-event recurrence interval and magnitude is needed for a complete understanding of ice stream dynamics, a critical element in assessing the future behavior of the West Antarctic ice sheet. Our analysis demonstrates that stick-slip variability is not well explained by a plastic model that assumes a constant yield stress. Instead, a time dependent-yield strength due to frictional healing after a slip-event, similar to that observed in laboratory studies of stick-slip phenomena, better explains the data. After a slip-event, stress at the glacier bed slowly increases due to the continued flow upstream. However, the rate at which stress accumulates at the bed is modulated by tidal fluctuations at the grounding line; during a falling tide, stress on the ice stream bed increases more rapidly than on the rising tide. In addition, the rate of stress accumulation varies throughout the spring-neap tidal cycle. Because our model has a time-dependent failure threshold, stress at the time of the slip-event varies, unlike a plastic model. This variation in stress explains the dependence of slip-magnitude on recurrence interval. Additionally, the time-dependent threshold model reproduces the observed recurrence times better than a plastic bed model. The observed behavior of Whillans ice stream indicates that basal shear strength can be dynamic at shot time scales, capable of changing by approximately ten percent over the course of a day.