Kennicott Glacier: A laboratory for the study of pulsed water delivery to the glacier bed

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Every summer, Hidden Creek Lake (HCL) drains over 2 - 3 days and delivers 20 - 30 × 10^6 m^3 of water to the hydrologic system running through and beneath Kennicott Glacier (Fig. 1). In the earliest 20^{th} century, industrial copper mining dominated the Kennicott Valley and the jökulhlaup, or outburst flood, would severely damage the shallowly-driven piles of the railway trestle which crossed the Kennicott River only 100 m downstream of the glacier terminus. But after this happened predictably over several years, engineers could have the railway repaired within 3 days of the flood by turning to a cache of stockpiled supplies.

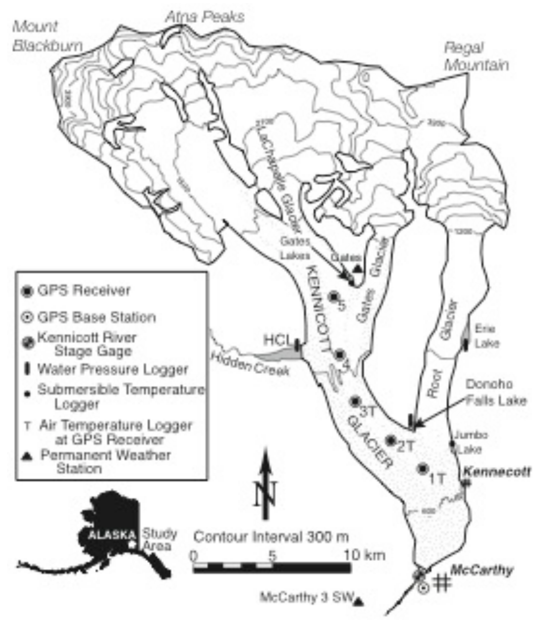

Fig. 1: Kennicott Glacier with the instruments installed during summer 2006.

Today, the National Park Service has replaced the Kennecott Copper Corp. as the valley's main tenant and a robust, steel bridge now replaces the delicate wooden trestle over the Kennicott River. HCL is roughly half the size it was and now drains on average two months earlier than it had 100 yrs ago. However, the predictability of the flood continues and this, along with the size (410 km^2) and relative accessibility of Kennicott Glacier, make Kennicott a near-ideal natural laboratory for the study of the links between glacier hydrology and glacier dynamics.

The glacier response to the jökulhlaup exemplifies much of what we presently understand about the links between glacier hydrology and basal motion (Fig. 2, Bartholomaus and others, 2011). Starting closest to HCL, the ice at each successive down-glacier, centerline GPS both accelerated and lifted vertically, apparently tracking the flow of HCL floodwater. Previously-drained ice marginal lakes refilled with the arrival of flood water and a geyser spouted several m into the air near the glacier edge, 4 km from the terminus. Once the HCL water reached the terminus, the glacier behaved as though a cork had been pulled from the pressurized

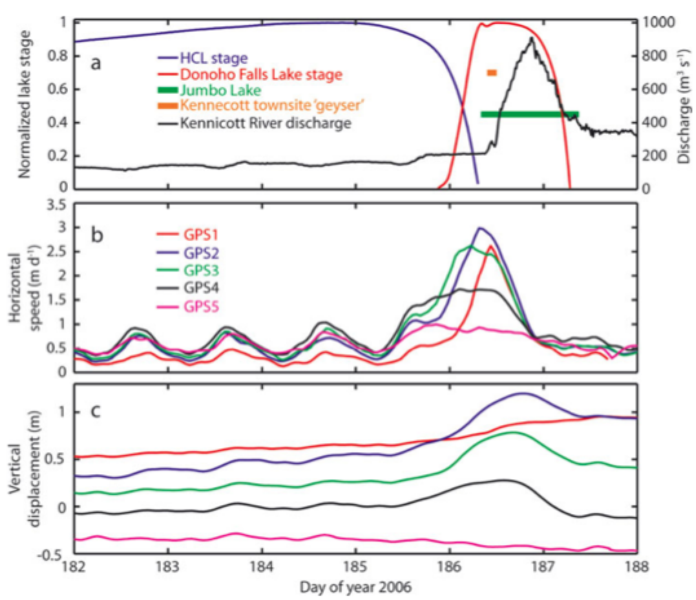

Fig. 2: Hydrology (a) and glacier motion (b, c) through the 2006 HCL jökulhlaup.

subglacial system. The ice at each GPS receiver decelerated simultaneously, the ice-marginal lake levels began to fall, and the geyser shut off. After two days, the diurnal velocity variations that had been present prior to the jökulhlaup resumed.

The ice dam in front of HCL acts as a secondary, lake-terminating Kennicott Glacier terminus. Ice flow within approximately 1 km of HCL is diverted toward the lake where it ultimately calves—particularly during lake drainage (Walder and others, 2006). The surface of the ice dam is dissected by nearly concentric crevasses that arc from valley wall to valley wall at the mouth of Hidden Creek. At 500 m from the lake edge, these crevasses slice through the entire 250 – 350 m glacier thickness and act as steeply dipping faults along which portions of the ice dam float on the rising and falling lake surface (Walder and others, 2005). This vertical motion reveals the presence of a wedge of subglacial water connected to HCL that stores up to 20% of the lake volume (Anderson and others, 2003a). By calculating a HCL water budget that includes water storage beneath the ice dam, Anderson and others (2003a) demonstrated that the lake seal does not leak prior to drainage.

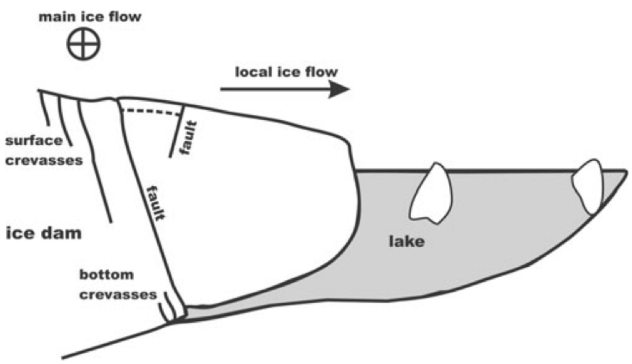

Fig. 3: Schematic cross-section of HCL and adjacent Kennicott Glacier ice dam. Lake water extends beneath a portion of the ice dam that is entirely severed from the main glacier by through-going crevasses.

Several studies have also considered longer timescale links between water and basal motion. In the Kennicott River, variations in solute concentrations may be used as a proxy for the water residence time at the glacier bed (Anderson and others, 2003b). Salt concentrations are low when water storage within the glacier is increasing and water passes quickly from the glacier surface to the outlet. Salt concentrations are high when water storage is decreasing and water drains slowly from an inefficient, distributed, subglacial hydrologic system. Bartholomaus and others (2008) built on this understanding by constructing a water budget of the Kennicott Glacier watershed to show that increasing water storage is associated with rapid glacier basal motion. They interpreted that this reflects large englacial water storage and thus high basal water pressures.

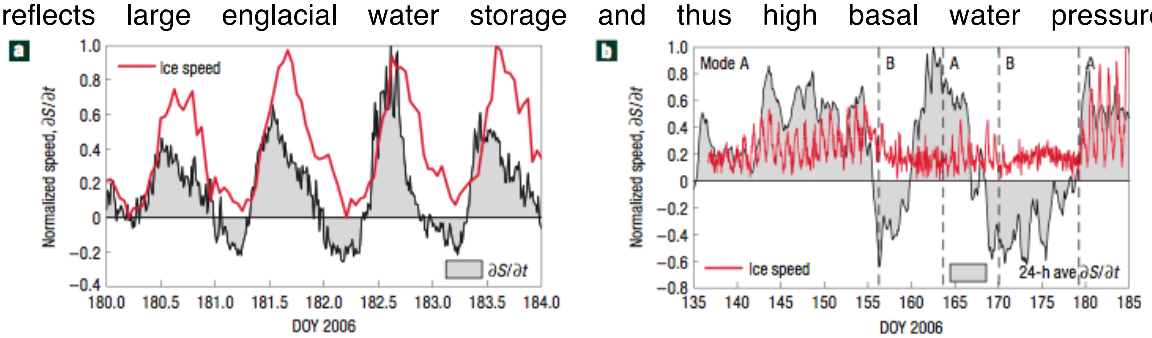

Fig. 4: Rate of change of glacier water storage (dS/dt) and ice speed near the center of Kennicott Glacier at both daily (a) and seasonal (b) timescales.

Anderson, S.P. *and 6 others.* 2003a. *J. Geophys. Res.,* **108(F1),** 6003. Anderson, S.P., S.A. Longacre and E.R. Kraal. 2003b. *Chem. Geol.,* **202(3–4),** 297–312. Bartholomaus, T.C., R.S. Anderson and S.P. Anderson. 2008. *Nat. Geosci.*, **1(1),** 33-37. Bartholomaus, T.C., R.S. Anderson and S.P. Anderson. 2011. *J. Glaciol.*, **57(206),** 985-1002. Walder, J.S. *and 6 others.* 2005. *Ann. Glaciol.,* **40,** 174-178. Walder, J.S. *and 6 others.* 2006. **52(178),** 440-450.