# Ice-shelf uplift during outburst flood events of ice-dammed lakes

## A viscous flexure model

by

Tyler Petillion

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE

in

The Faculty of Science

(Geophysics)

THE UNIVERSITY OF BRITISH COLUMBIA

(Vancouver)

April 2020

# Chapter 1

# Introduction

## 1.1 Glacier outburst floods

Glacier outburst floods, or 'jökulhlaups', are sudden releases of large amounts of water from a glacier. These outburst floods exhibit significant increases in meltwater discharge over a period of minutes to several weeks and at the terminus, discharge may increase by as much as an order of magnitude (Roberts, 2005; Post and Mayo, 1971). Glacier outburst flood frequencies are expected to increase the next decades and into the 22nd century (Richardson and Reynolds, 2000; Harrison et al., 2018).

70% of all recorded glacier floods occurred from the failure of ice-dammed lakes (Carrivick and Tweed, 2016). The existence of ice-dammed lakes is documented for most presently glaciated areas and present global deglaciation is increasing the number, and extent of ice-dammed lakes around the world (Carrivick and Tweed, 2016; Tweed and Russell, 1999). These ice-dammed lakes can effect considerable geomorphic change in glacial environments because of the recurrent or occasional release of the water stored within them. Damages of infrastructures can occur up to tens to hundreds of kilometers downstream and Of 1348 recorded glacier floods, 24% had a societal impact recorded (Carrivick and Tweed, 2016).

## 1.2 Current model work on ice-dam failure

The basic physics of how ice-dammed lake floods progress once initiated is relatively well understood. Glacier-dammed lakes produce outburst floods through the thermal erosion of a subglacial conduit, driven by water flow fed by the lake as a reservoir that keeps water pressure in the conduit relatively constant during the initial growth of the conduit, suppressing the creep closure of the conduit that could otherwise prevent the channel from enlarging (Nye, 1976; Röthlisberger, 1972). The classical model has been widely successful in simulating many observed features of outburst floods (Fowler, 1999; Bjornsson, 1992).

The initiation of the flood, however, is less well-understood. Nye (1976) Describes ice-dammed lakes as confined by a "seal" which is maintained by the overburden pressure of the ice surrounding. The lake is sealed until it reaches a critical level which enables it to lift the glacier, helped by a hydrostatic cantilever effect. Many studies forego the cantilever effects and adopt a simple criterion of flotation. This criterion is based on Archimede's principle. Where, if the buoyant force is greater than or equal to the ice column, the ice will float. Likewise, if the weight of the ice column is greater that the buoyant force beneath it, the ice will remain grounded. This relationship suggests that the critical lake level that enables flotation is roughly 90% of the ice's depth (based on the ice to water density ratio). While flotation is a frequently cited drainage trigger mechanism, predictions of outbursts based on ice-dammed lakes attaining 90% of the height of ice dams are often inconsistent with the actual lake level at which drainage occurs (eg. Bigelow et al., 2020; Anderson et al., 2003; Sugiyama et al., 2008).

## 1.3 Case study

This thesis builds on the observations from the Kaskawulsh glacier in Bigelow et al. (2020). In particular, we examine the delayed on-set of flooding relative to simple flotation, as well as the lag between peak lake level and maximum uplift of the shelf (Figure 1.1). In examining Figure 1.1, the lake depth (blue) reaches a maximum and begins to drain at a lake level of 70 m on August 18th, 2017. Theoretical flotation of the ice (green) is shown to reach is maximum at the same date as the lake maximum and has begun to float by July 17th.

The GPS uplift data (black) shows that the ice reaches its maximum uplift at later date of August 24th, 2017. In fact, as the drainage event

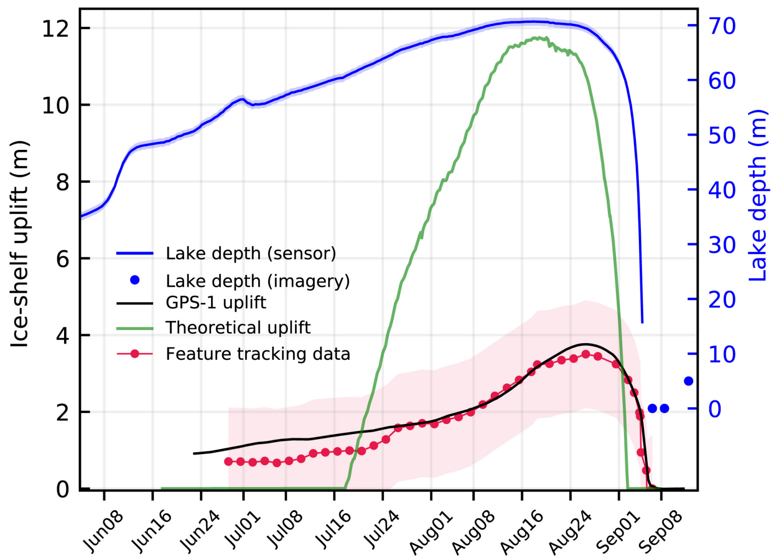


Figure 1.1: Observational and theoretical data from the Kaskawulsh glacier, Summer 2017. Lake depth (right axis) and vertical ice shelf uplift (left axis). Measured GPS ice shelf uplift (black), compared to estimated ice shelf uplift at the same position from feature tracking (red), and theoretical uplift assuming flotation of the ice column (green) (left axis). The shaded region shows the estimated error in ice shelf uplift. Lake depth data is shown in blue (right axis). (From Bigelow et al. (2020))

begins, the ice is continuing to rise.

## 1.4 Thesis structure

The objective of this thesis is to model the viscous flexural response of an ice-dam as a means to explain the discrepancy in timing between the observed and theoretical vertical displacement of the ice. In particular, we examine the effects of a bending moment causing ice uplift before the condition of Archimedean flotation. We also examine the effects of a bending moment on the timing of maximum uplift along an ice profile.

First, we present the model geometry and the relevant differential equations defining the motion of an ice-dam. We then scale the model and present an iterative Finite Element approach to solve the system of equations. In doing so, we find that the bending moments cause the ice, with the exception of the calving front, to uplift sooner than that modeled in the Archimedean case. We also find that the flexural response of the ice causes the timing in ice uplift maximums of ice far from the calving front to lag those of the ice near the calving front.