Parsimonious hydroglaciological modeling for understanding the hydrological role of rock glaciers in the Andes of Central Chile

Luis Marcoleta[(1)] & James McPhee[(1),(2)]

(1)University of Chile, Department of Civil Engineering

(2)Advanced Mining Technology Center

UNIVERSIDAD DE CHILE

Abstract

Glaciers are purported to play a key role in the hydrology of the semi-arid Andes of Central Chile and Argentina, where the presence of debris-covered glaciers (DCG) and rock glaciers (RG) has been largely documented and in some cases surpasses the extent of debris-free glaciers (DFG). However, studies quantifying their hydrological contribution are still few. In this work, we build a hydrological model for the Yerba Loca Creek basin which hosts glaciers of different types (DFG, DCG and RG). We use the Cold Regions Hydrological Model (CRHM), with modifications including: (i) an offline process to calculate the melting from DCG,(ii) annual ice mass redistribution from upper to lower Hydrologic Response Units (HRUs) based on the ice flow equations, focused on DFG. The results of this study have wide implications to the estimation of water resources for mountain. The results shows that the contribution of covered glaciers is around 10% to 20% of total glacier contribution; and an improve in the ice mass balance and distribution.

Introduction

- Glaciers are purported to play a key role in the hydrology of the semi-arid Andes in Central Chile and Argentina.
- Ayala et al. (2016) have modeled the glaciar contribution with an enhanced temperature index model, showing a contribution of 67% during the driest year.
- We have applied a physically based method to calculate the contribution of debris covered and rock glaciers. For debris-free glaciers, we applied an ice flow equation to update the ice distribution
- Grid data from a reanalysis from the Chilean water balance update

Study Area

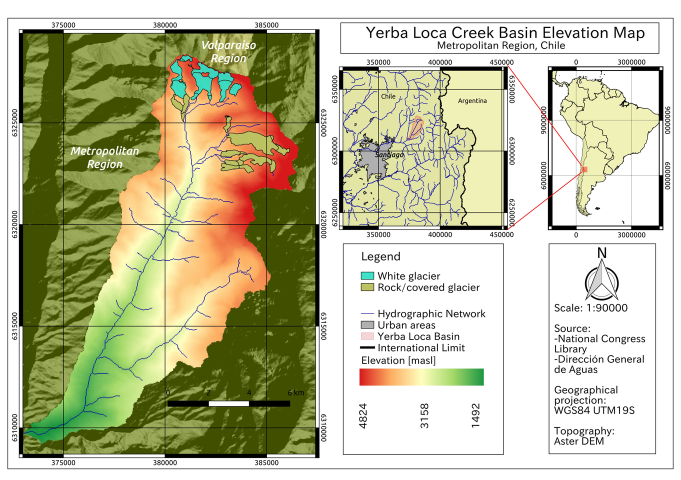

Figure 1:Yerba Loca Creek Basin elevation map

- Area: 108.8km^2
- Total glacier area: 6.8km^2 (6.2%)
- Debris covered/rock glaciers area: 3.8km^2 (55% of total glacier)

Debris covered equations

Tested:

- Nicholson and Benn (2006)
- Reid and Brock (2010) **(Selected)**
- Carenzo et al. (2016)
- Changwei and Gough (2013)

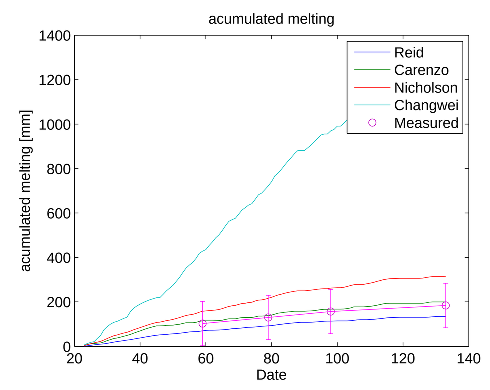

Figure 2:Litoria glacier melting validation

Reid and Brock (2010) energy balance equation (solved calculating the internal debris temperature gradient):

$$S + L\downarrow + L\uparrow(T_s) + H(T_s) + LE(T_s) + G(T_s) + P(T_s) = 0$$

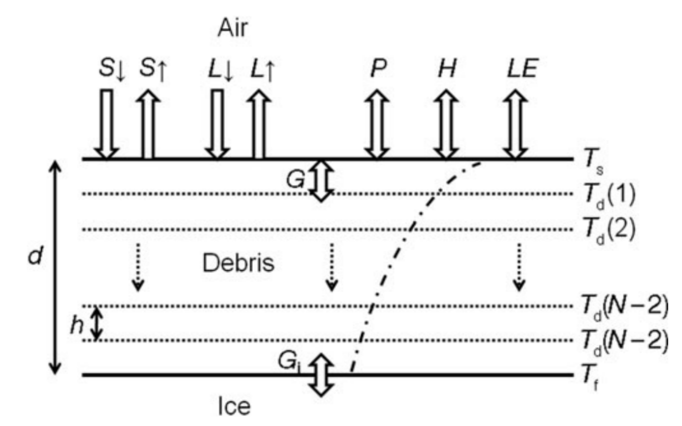

Figure 3:Schematic of the DEB model.(Source: Reid and Brock (2010))

Ice Flow equations

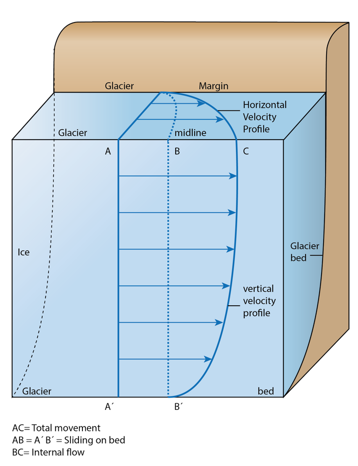

Figure 4:Schematic glacier flow components

Basal flow (Paterson, 1970):

$$u_b = 0.11h^{0.95} \quad (1)$$

Deformation (Hooke, 2005):

$$U_x = \frac{2A}{n+1}(\rho g \sin\alpha)^n H^{n+1} \quad (2)$$

Validation:

Ice flow[m/year]	Paloma	Altar sur
Observed	8	7.3
Calculated	6.7	5.99

Table 1:Ice flow validation

Debris covered glaciers Results

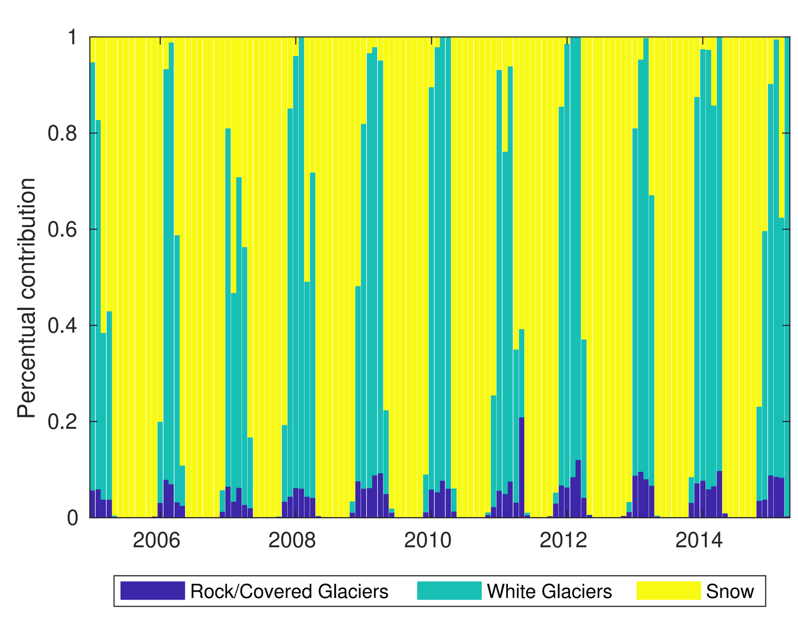

Figure 5:Percentual melting contributions

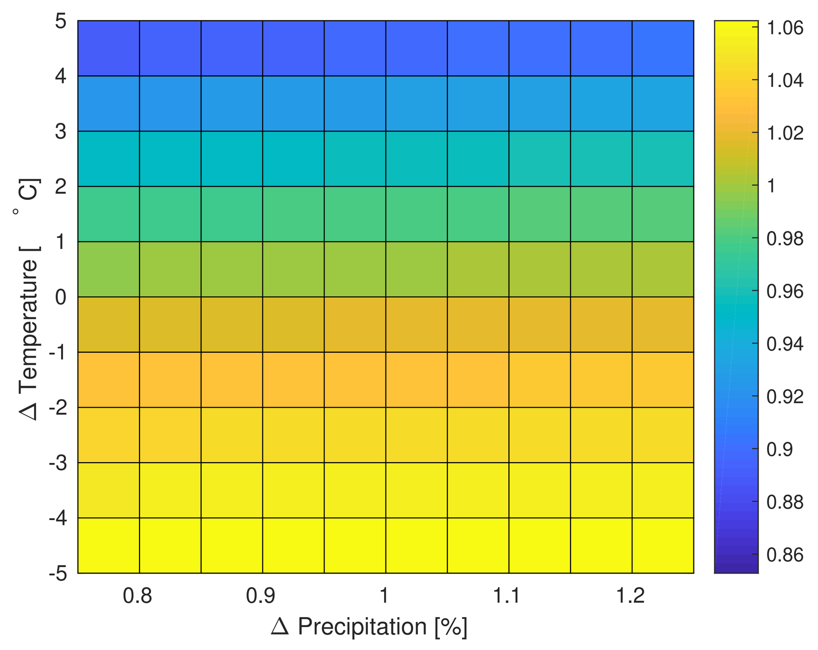

Figure 6:Ice variation with changes of temperatura and precipitation

Ice Flow Results

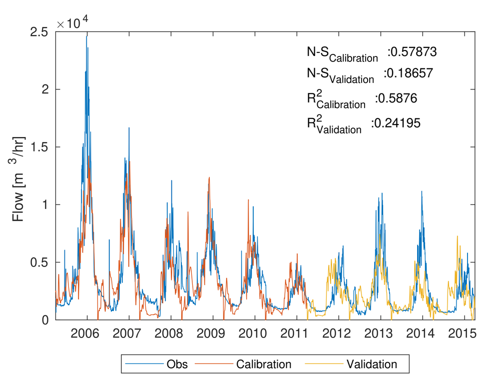

Figure 7:Daily Flow considering Ice Flow

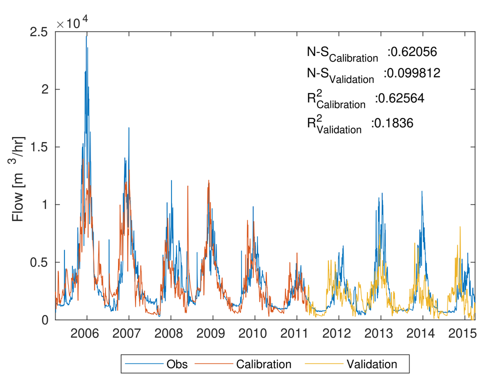

Figure 8:Daily Flow not considering Ice Flow

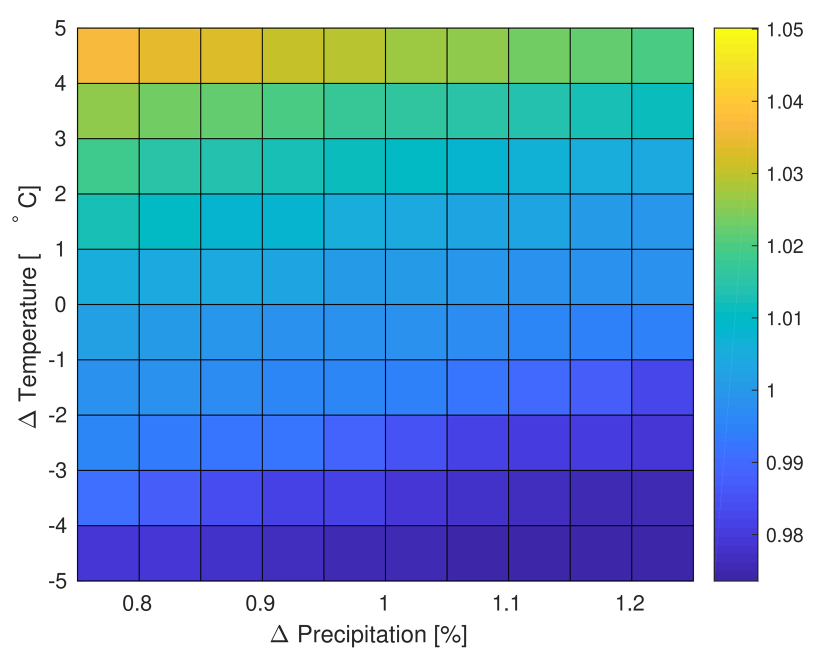

Figure 9:Ice variation comparisson considering and not considering Ice FLOW ($\Delta WithIceFlow/\Delta NoIceFlow$)

Conclusions

- Significant contribution of Debris covered and Rock glaciers (up to 17%).
- Earlier and longer contribution from debris covered and rock glaciers than debris free glaciers.
- More sensitive behavior to temperature changes than precipitation.
- Not a big improve in the flows representation including the ice flow, but an important change in the ice volumes.
- The inclusion of the ice flows seems to represent a more resilient glaciers.

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Contact: luis.marcoleta.r@gmail.com