10 pages long with figures

# Introduction

Give a background explanation of the processes that are being studied (with relevant references). In this context, explain your question(s) and its significance.

The sensitivity of glaciers to climate results in an augmentation of ablation compared to accumulation when temperature rises, increasing surface meltwater available for infiltration through crevasses and moulins and potentially impacting the movement of the glacier (Benn & Evans, 2010). Particularly, the Greenland Ice Sheet (GrIS) is a subject of concerns, as it represents 10 percent of the total Earth’s freshwater, could elevate oceans by 6.5 m (Benn & Evans, 2010) , and is influenced by global warming since 1990 by an increase in temperature inducing increased surface melting (Hanna et al., 2008).

The relationship between surface meltwater infiltration and acceleration or deceleration of the iceflow in the GrIS is currently a subject of debate. Zwally et al. (2002) suggested that increase in melt will potentially dramatically accelerate the ice flow. With one point of GPS measurement, they found seasonal and annual correlation between ice motion and the potential meltwater produced (with a positive degree-day indicator). They suggest this speedup results from the decrease of the effective pressure when infiltration increases, increasing sliding at the bed.

Further research made with a larger number of GPS units (Bartholomew et al., 2011; Hoffman, Catania, Neumann, Andrews, & Rumrill, 2011; Sole et al., 2013) showed that, if summer acceleration was correlated with increase of surface meltwater, winter deceleration was inversely correlated, meaning that the more the melt in the summer, the stronger the deceleration will be in winter, invalidating the annual correlation between melting and acceleration. This early deceleration was explained by the enlargement of subglacial drainage leading to lowered water pressure, increased effective pressure, and creep closure of subglacial conduits. Later, Andrews et al. (2014) monitored drillholes and a moulin and found contradicting results and hypothesized that the channelization of unconnected areas was the cause of the increase of effective pressure, instead of the enlargement and collapsing of the conduits under the weight of the glacier.

Meltwater influence over ice motion is still incompletely understood and monitoring moulins is underrepresented on the GrIS in previous studies even though it permits direct measurement of the water level and the dynamics of the glacier. Moulins are connected to the bed and can give precious information to understand how surface meltwater infiltration in moulins influences the acceleration rate of the Greenland Ice Sheet motion. To understand the measured fluctuation induced by meltwater into the moulins, it is crucial to identify the fluctuation of the head induced by other physical mechanism in action in the moulin. As the head varies with time, the relation between the ice thickness and the head drives conduit evolution and transport of water underneath the glacier.

To identify the different timescales of the variation of the head in the moulins, we model a simple reservoir-conduit system with head-related variation of conduit (Covington et al., 2012)

# Methods

Summarize your model and the modeling methods that you used.

# Results

Present the results of your modeling in a factual way, without added interpretation

# Discussion

Develop an interpretation of your results and address your initial question(s). Explain any limitations to the interpretation, as well as any broader implications.

# Conclusion

Summarize the conclusions of your study

To understand moulins' interactions with meltwater, residence time in the moulin and variation of the size of the output, we plan to test a model reproducing water level in the moulin.

To reproduce the water level fluctuation in moulins, the reservoir constriction equation is used. It is composed of the open channel equation (Figure 1b) to simulate the vertical variation of water in the conduit, and the full pipe equation (Figure 1a) to constrain the output of the moulin in the interface of the ice with the bedrock. (Covington et al., 2012)

A first set of equation will describe how waterlevel changes in the moulin as well as the discharge in the output conduit.

(1)

(2)

Where *Ar* is the reservoir surface area, *Q* is the volumetric discharge, *R* is the recharge, *h* is the depth of water in the reservoir, *Ac* is the cross sectional area and *Cf* is a constant that account for energy loss (Eqs. (24) and (25) in Covington et al., (2009)). (Covington et al., 2012)

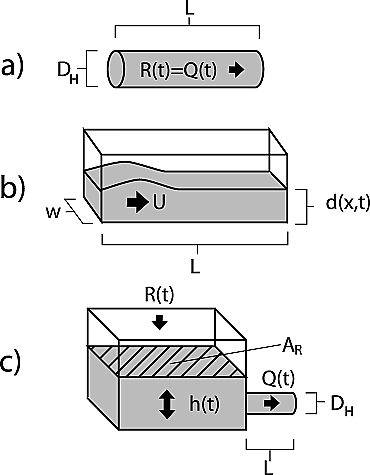


Figure 1. Reservoir constriction. a) full pipe, b) open channels c) reservoir constriction (Covington, Wicks, & Saar, 2009).

A second set of equation will simulate the melt and creep in regard of the discharge.

(3)

where *ρw* and *ρi* are the density of water and ice, *Lf* is the latent heat of fusion of water, *Pwet* is the conduit wetted perimeter, *n* is the ice flow law exponent, *B* is the Arrhenius parameter, and *Pw* and *Pi* are the conduit water pressure and ice overburden (Eq. (6) in Covington et al., 2012). (Covington et al., 2012)

R, the flow into the moulin is fixed, h and the diameter of the output conduit will have an initial condition.

The objective is to see how, with a fixed flow rate, the water level evolve in the moulin and identify different variation and the timescale. This will permits to identify patterns potentially visible in data taken in the moulins on the GrIS, and differentiate it with recharge variation. One of the goals is to see if the system reaches equilibrium, as it is currently assumed.

Timeline:

Nbr of week to the final report: 9

Nbr of week per task:

Equation in Python: 2 (weeks 7-8)

Graph production: 1 (weeks 9)

Result interpretation: 2 (weeks 10-11) – Midterm report (week 11)

Comparison with data: 2 (weeks 12-13)

Report writing: 2 (weeks 14-15)

Final report week 16

References:

Covington, M. D., Banwell, A. F., Gulley, J., Saar, M. O., Willis, I., & Wicks, C. M. (2012). Quantifying the effects of glacier conduit geometry and recharge on proglacial hydrograph form. *Journal of Hydrology*, *414*, 59–71. https://doi.org/10.1016/j.jhydrol.2011.10.027

Bartholomew, I., Nienow, P., Sole, A., Mair, D., Cowton, T., Palmer, S., & Wadham, J. (2011). Supraglacial forcing of subglacial drainage in the ablation zone of the Greenland ice sheet. *Geophysical Research Letters*, *38*(8), L08502. https://doi.org/10.1029/2011GL047063

Benn, D., & Evans, D. J. (2010). *Glaciers and glaciation* (Second edition). New York, NY: Routledge.

Covington, M. D., Banwell, A. F., Gulley, J., Saar, M. O., Willis, I., & Wicks, C. M. (2012). Quantifying the effects of glacier conduit geometry and recharge on proglacial hydrograph form. *Journal of Hydrology*, *414*–*415*, 59–71. https://doi.org/10.1016/j.jhydrol.2011.10.027

Covington, M. D., Wicks, C. M., & Saar, M. O. (2009). A dimensionless number describing the effects of recharge and geometry on discharge from simple karstic aquifers: DIMENSIONLESS NUMBER FOR KARST AQUIFER RESPONSE. *Water Resources Research*, *45*(11). https://doi.org/10.1029/2009WR008004

Hanna, E., Huybrechts, P., Steffen, K., Cappelen, J., Huff, R., Shuman, C., … Griffiths, M. (2008). Increased Runoff from Melt from the Greenland Ice Sheet: A Response to Global Warming. *Journal of Climate*, *21*(2), 331–341. https://doi.org/10.1175/2007JCLI1964.1

Hoffman, M. J., Catania, G. A., Neumann, T. A., Andrews, L. C., & Rumrill, J. A. (2011). Links between acceleration, melting, and supraglacial lake drainage of the western Greenland Ice Sheet. *Journal of Geophysical Research: Earth Surface*, *116*(F4), F04035. https://doi.org/10.1029/2010JF001934

Sole, A., Nienow, P., Bartholomew, I., Mair, D., Cowton, T., Tedstone, A., & King, M. A. (2013). Winter motion mediates dynamic response of the Greenland Ice Sheet to warmer summers. *Geophysical Research Letters*, *40*(15), 3940–3944. https://doi.org/10.1002/grl.50764

Zwally, H. J., Abdalati, W., Herring, T., Larson, K., Saba, J., & Steffen, K. (2002). Surface Melt-Induced Acceleration of Greenland Ice-Sheet Flow. *Science*, *297*(5579), 218–222. https://doi.org/10.1126/science.1072708