Sensitivity of glacier towards climate results in an augmentation of ablation compare to accumulation when temperature rises, augmenting surface meltwater available for infiltration through crevasses and moulins and potentially impact the movement of the glacier (Benn & Evans, 2010). Particularly, the Greenland Ice Sheet (GrIS) is a subject of concerns, as it represent 10 percent of the total Earth's freshwater and 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 subject of debate and has been first put forth by Zwally et al. (2002) who alerted the scientific community and general public that increase in melt will potentially dramatically accelerate the ice flow. With one point of GPS measurement, they found seasonal and annual correlation between the potential meltwater produced (with a positive degree-day indicator) and explained it with the diminution of the effective pressure on the ice when infiltration increase, allowing sliding at the bed.

Further research made with a wider number of GPS (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.

Monitoring moulins is underrepresented on the GrIS in previous studies even though the fact that 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 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)

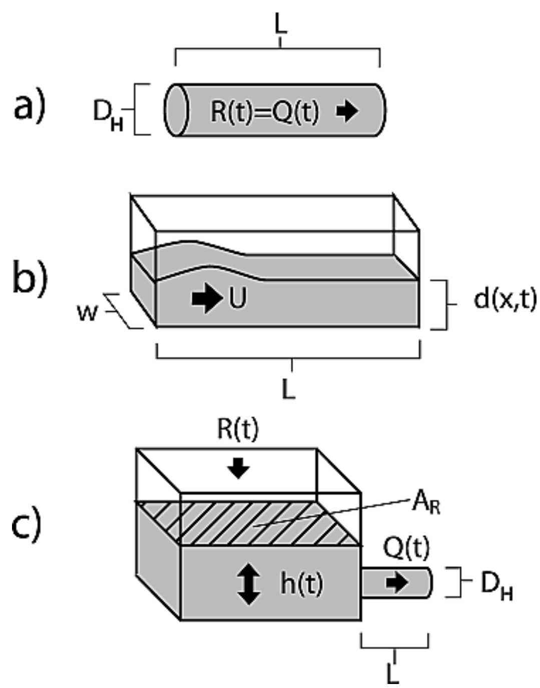


**Figure 1. Reservoir constriction. a) full pipe, b) open channels c) reservoir constriction (Covington, Wicks, & Saar, 2009).**

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

$$\frac{dh}{dt} = \frac{R-Q}{A_R} \tag{1}$$

$$Q = A_c\sqrt{\frac{2gh}{C_f}} \tag{2}$$

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

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

$$\frac{dA_c}{dt} = \frac{f\rho_w}{8\rho_i}\frac{P_{wet}Q^3}{A_c^3} - 2\left(\frac{1}{nB}\right)^n A_c(P_i - P_w)|P_i - P_w|^{n-1} \tag{3}$$

where $\rho_w$ and $\rho_i$ are the density of water and ice, $L_f$ is the latent heat of fusion of water, $P_{wet}$ is the conduit wetted perimeter, $n$ is the ice flow law exponent, $B$ is the Arrhenius parameter, and $P_w$ and $P_i$ 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 there 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:

Andrews, L. C., Catania, G. A., Hoffman, M. J., Gulley, J. D., Luthi, M. P., Ryser, C., … Neumann, T. A. (2014). Direct observations of evolving subglacial drainage beneath the Greenland Ice Sheet. *Nature*, *514*(7520), 80–83. https://doi.org/10.1038/nature13796

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