# Investigating the relationship between the hydrology and velocity of the Leverett Glacier, west Greenland

## Introduction

This project aimed to investigate the relationship between the hydrology and velocity of an outlet glacier, draining the western flank of the Greenland Ice Sheet (GrIS). Specifically, the primary aim was to

'Assess seasonal variations in ice velocity and how this relates to temporal variations in meltwater production and the efficiency of the subglacial drainage system.'

The results should prove useful for assessing the response of the Leverett Glacier to variations in temperature and meltwater generation, particularly in relation to climate change. Recent research suggests that rising temperatures will lead to increased ice velocity due to increased meltwater raising subglacial pressure and therefore basal sliding (Bartholomew et al 2010). This could lead to the GrIS substantially raising sea-level (Parizek and Alley 2004). However, the relationship is highly complex (Schoof 2010) and it has been suggested that warming could in fact reduce ice velocity (Sundal 2011).

## Methods

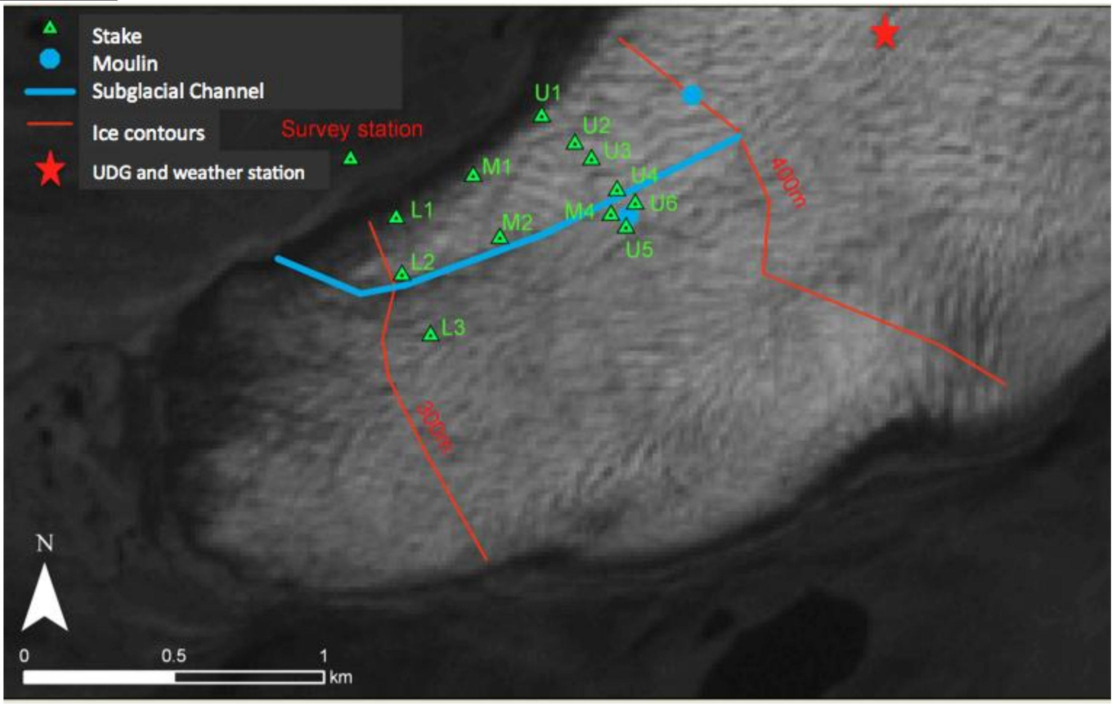


**Fig 1:** Glacier and stake layout

To ascertain the velocity of the glacier, a Trimble 5605 surveyor was used to monitor the changing position of stakes between surveys. A network of velocity stakes was established on the glacier (fig.1) in late April and measured almost daily until mid-August. I carried out all surveys during my time at camp. This method supplied a sufficient level of accuracy, with the main threats being human error and ablation causing the survey stakes to tip over.

A temperature-index model as described by Hock et al (2003) was used to calculate daily surface melt throughout the season, based on temperature. This method was sufficiently accurate for its purpose, with relative changes being most important.

Bulk discharge data was provided for me by other researchers, and was measured throughout the day in a proglacial river.

## Results

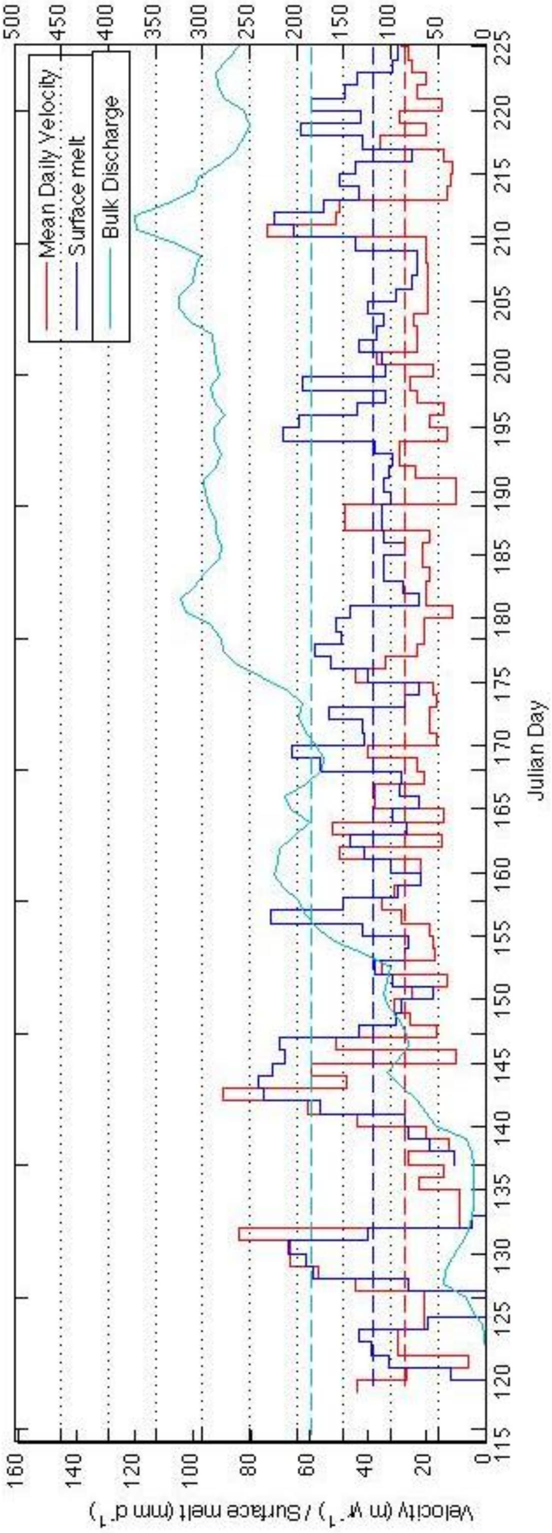


**Fig 2:** Mean daily velocity for all stakes plotted along with daily modelled surface melt and mean daily bulk discharge for the whole study period. Dotted lines represent mean values for whole period.

Following the onset of melt, two periods of freezing conditions followed, within fifteen days. Beyond this, melt conditions were present for the remainder of the season. Melt rapidly restarted after two days of freezing conditions, hitting amongst the highest levels of the season from day 128 to 130, before temperatures plummeted again below 0°C. Melt rose rapidly again as it entered the greatest melt period of the summer from days 142 to 146, peaking at 78mm $d^{-1}$ on day 143. It then declined by 57% to 31mm $d^{-1}$ within two days. Significant variations occurred for the rest of the season. A notable melt increase of 211% occurred between day 208 and 211.

The onset of bulk discharge lagged local surface melt but increased throughout the season, notably in three large steps.

A mean of daily velocity across all stakes conveys a seasonal pattern. The mean velocity was 29m $yr^{-1}$, with most values lying between 10m $yr^{-1}$ and 40m $yr^{-1}$. High velocity events are distinct within the season, particularly two events in spring. Velocity rapidly increased from 21m $yr^{-1}$ on day 126 to 84m $yr^{-1}$ on 131. Later in spring, velocity again rapidly increased by 567% over four days to the seasonal peak of 90m $yr^{-1}$ on day 142. A distinct spike also occurred in late July, peaking at 75m $yr^{-1}$ on day 210 and high values continuing for a further two days. This event was the third highest of the season, and higher than any since May.

<u>Discussion and analysis</u>

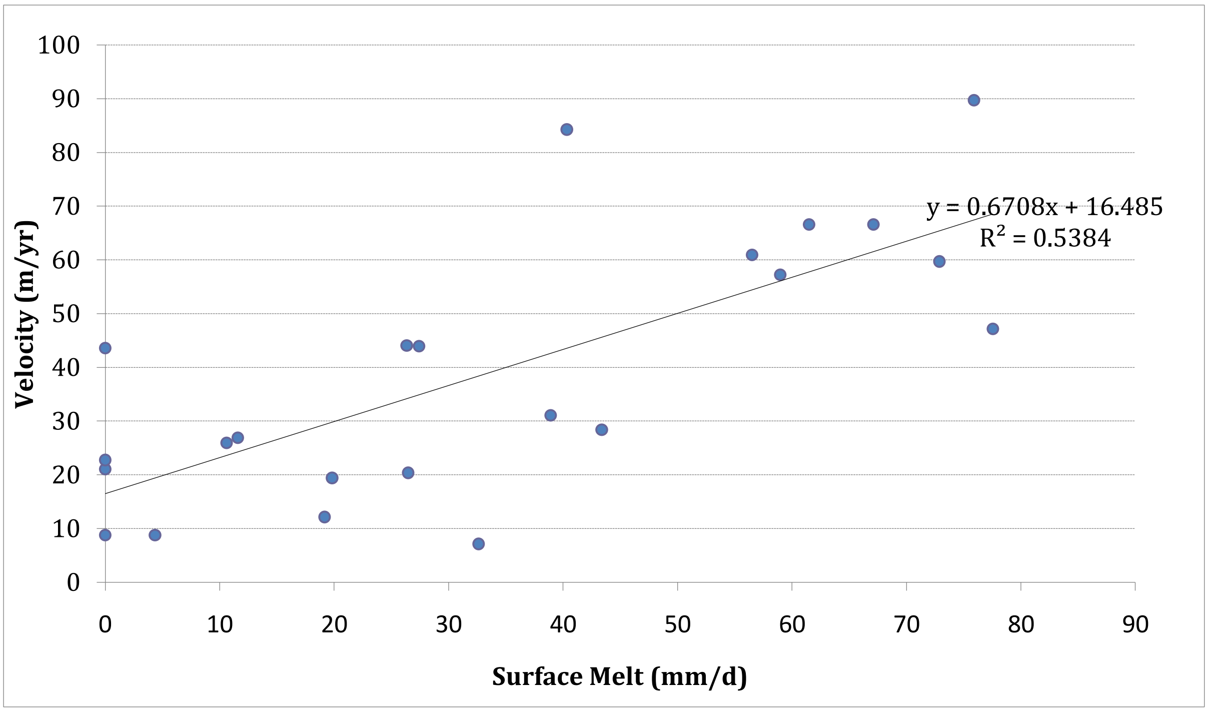


**Fig 3:** Mean daily velocity across all stakes plotted against modelled surface melt for days 119 to 144

In contrast to the relationship across the whole season, between days 199 and 144, surface melt and velocity were strongly and significantly correlated with a correlation coefficient of 0.73 (P<0.01). This corresponds to the phase 2 identified by Bartholomew et al (2010), where velocities were high following melt onset, and were strongly coupled with melt. Such an increase in velocity necessitates that basal sliding was predominantly driving velocity. The positive reaction of velocity to meltwater input during this phase suggests that the subglacial drainage system comprised of a distributed, inefficient system. For a melt-velocity relationship to exist and the velocity to respond on the same day it suggests a hydrological connection between the surface and the base had been established. This would allow surface melt to be transported through small conduits to the base and inhibit creep closure, promoting the formation of cavities. This distributed drainage network would then have been sustained by increasing meltwater supply increasing the hydrological pressure, thus facilitating enhanced cavitation and therefore reduced friction and basal sliding.

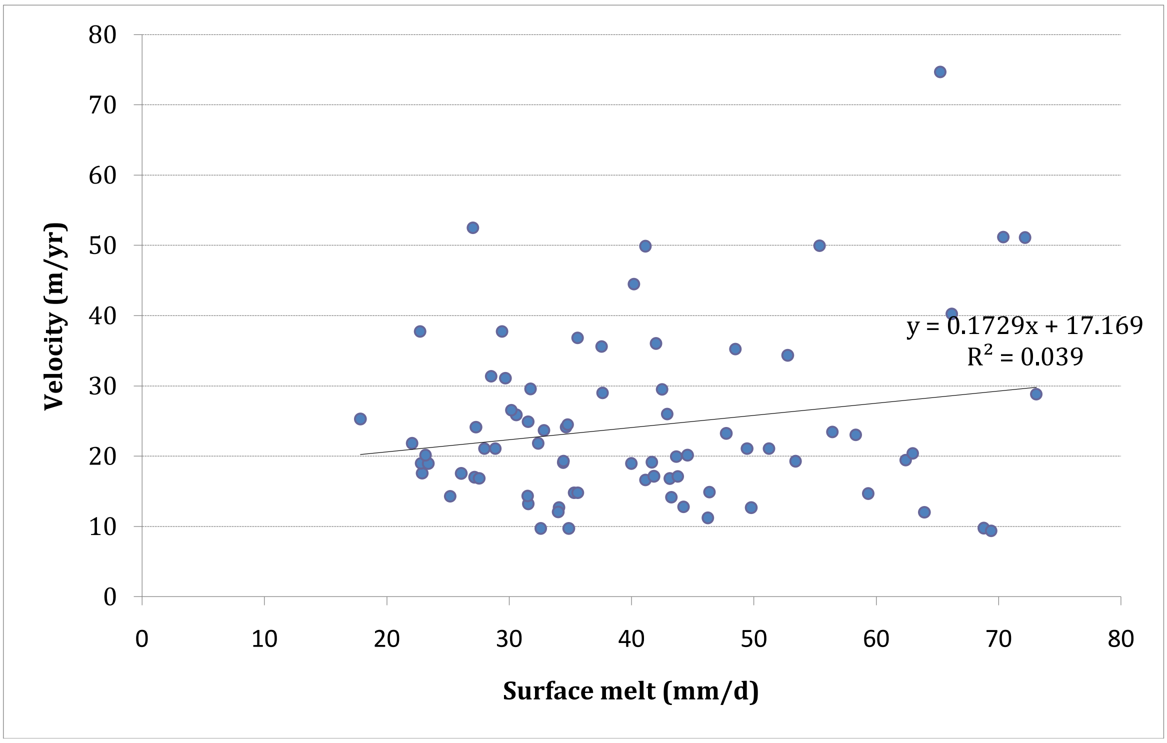


**Fig 4:** Mean daily velocity across all stakes plotted against modelled surface melt for days 145 to 224.

From day 145, the correlation between surface melt and velocity was both weaker and less significant, with a coefficient of 0.20 (P<0.05). This suggests decoupling following rationalization of the drainage system. The data suggests that discharge during the peak velocity and melt event of days 140-144 exceeded a critical discharge level. The surpassing of this threshold appears to have switched the hydrological system to an efficient, channelized one. Establishment of a channelized drainage-system, explains the plummeting of velocity following the spring event, on days 145-147, despite melt remaining high for a further four days. The enhanced melt continued channel growth by wall melting, promoting increased effective pressure to offset the process, thus reducing cavitation and basal sliding.

Despite the efficiency of the subglacial drainage system, a high melt event on days 210-212 caused a substantial increase in velocity from 21m $yr^{-1}$ on day 209 to 124m $yr^{-1}$ on day 210, with velocity maintained at 75m $yr^{-1}$ over the subsequent two days. The event can be attributed to a caveat in Schoof's (2010) model, neglected by Sundal et al (2011) when asserting that warming will reduce ice velocity. Crucially, the inverse discharge-pressure relationship observed in channelized drainage systems only exists when in steady-state. It appears that on days 210-212 the rapid increase in discharge overwhelmed the capacity of the channel to adjust, requiring an increase in basal pressure.

Acknowledgements
I am very greatful to the Mackay Greenland Fund for their extremely generous grant, which covered my flights and food for the duration of my 'successful' expedition. Costs were higher than anticipated due to an incident on my first day where I broke my arm, which made the grant even more crucial. I also appreciate assistance from Dr Pete Nienow, Dr Andrew Sole, Tom Cowton. Countless people in Kangerlussuaq and Nuuk were a great support during my recovery.

Itinerary

Feb-May 2010: Project inception and planning
June 2010:
- 2nd-23rd Intended fieldwork period
- 2nd-16th Arrival and recovery following accident on 2nd

July 31st-August 15th: Return trip, fieldwork throughout stay
September 2010 – March 2011: Writing, data processing and interpretation

Personal statement

My experience in Greenland was invaluable and cemented my desire to work towards a career in glaciology. I will also be building upon this experience with a trip to the same site in summer 2011, as a field assistant for Bristol University. As well as direct experience with field equipment, which I was able to utilise just a month later during my research elective in Iceland, I gained crucial experience working in a dynamic environment that requires constant adaptation. Faultering equipment and changing conditions meant one had to be creative in overcoming obstacles and ensure regular, reliable data collection. Working in a team, particularly with people I did not previously know, honed my communication and leadership skills. I was privileged to be working with a diverse group of leading scientists, who I hope to have learned from. Additionally, I had to spend long periods alone, working throughout the night, which was both daunting and rewarding. My time in Kangerlussuaq and Nuuk also proved a learning experience, as I was forced to deal with important and complicated issues in an environment where few spoke the same language as me. I remain in contact with several people I met during this time.