Cracow, September 22nd, 2023

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Review of the PhD dissertation: *"Functioning of Svalbard glacier drainage systems from in-situ data, remote sensing, and models" by Léo Decaux*

The basis for preparing this review is the letter from the Director of the Institute of Earth Sciences at the University of Silesia in Katowice, Ewa Łupikasza, dated July 18, 2023, prepared based on the resolution of the Scientific Council of the Institute of Earth Sciences at the University of Silesia in Katowice dated July 6, 2023, regarding the appointment of reviewers in the doctoral procedure of Léo Decaux. The supervisors of the thesis are Mariusz Grabiec and Kenneth D. Mankoff.

The topic of the doctoral dissertation and research objectives

The dissertation presented to me for review focuses on the issue of the impact of the glacier drainage system on its dynamics. In the time of climate warming, we currently observe increased intensity of ice melting on Spitsbergen glaciers, thus justifying the thesis about the evolution of the meltwater drainage system. Consequently, the question of how the increased supply of meltwater affects the glacier's sliding speed seems justified. More specifically, it remains an open question how does the drainage system change in the case of a significant extension of the ablation season and intensified melting in the autumn season, when typically the drainage system was already empty, and englacial channels and moulins were accessible?

This work represents an attempt to address these issues, and the doctoral candidate has taken on the bold task of studying what is invisible to our eyes, hidden beneath the ice surface, even in an era of extremely rapid satellite measurement development. Connecting the results of meltwater pressure measurements in moulins or englacial channels with changes in the supraglacial drainage network and glacier dynamics is undoubtedly an ambitious task. It required, above all, a significant commitment from the doctoral candidate, mostly in challenging yet exciting spaleoglaciological fieldwork. At the same

time, the technical achievements related to the installation of pressure/water level sensors deserve recognition, as they allowed for obtaining unique data on the fluctuations in englacial water levels in a polythermal glacier.

The thesis defines multiple objectives as follows: to characterise the permanency of the supraglacial drainage system; to determine the influence of the supraglacial drainage system on the subglacial system; to continuously measure in-situ englacial channel water fluctuations for at least one hydrological year; to comprehend the englacial channel water fluctuations over the entire hydrological year; to establish direct connections between observations of englacial water fluctuations within the channelised system and the speed of the glacier; and finally, to identify the effect of warm winter events on the IDS and its impact on glacier speed.

I have no doubts regarding the motivation for undertaking this research and the significance of the presented research objectives, as well as the novelty of the conducted in situ measurements.

The structure of the doctoral dissertation

The thesis has an unconventional, hybrid structure that combines a monograph with a series of two articles, presented as appendices:

[I] **Decaux, L.**, Grabiec, M., Ignatiuk, D., Jania, J.: Role of discrete water recharge from supraglacial drainage systems in modeling patterns of subglacial conduits in Svalbard glaciers, *The Cryosphere*, 13, 735–752, 2019.

[II] **Decaux, L.**, Mankoff, K. D., Grabiec, M., Tuszynska, J., Luks, B., Jania, J. A.: Sustained high winter glacier velocities from brief warm events, *Authorea Preprints*, 2022.

The monograph is essentially an expanded compilation of Article I and of a clearly modified preprint version of the Article II. Apparently, the manuscript of the Article II was not well received by the reviewers in GRL (it has not been published to date), which may indicate significant shortcomings in its content. Consequently, such structure of the thesis results in formal difficulties in separating the contribution of the doctoral candidate from that of other co-authors, leading to a certain acrobatics in the description of data and methods, where the doctoral candidate lists the co-authors by name when describing the sections related to their work. In my opinion, this approach has effectively separated the doctoral candidate's contribution to the creation of this thesis and the presented results. However, it reduces the readability of the text and makes it more challenging to focus on what is essential. Nevertheless, in both articles, the doctoral candidate is the first and lead author. According to the attached statements, the percentage contribution of Léo Decaux to the creation of these articles has been estimated at 85% and 85.8%, respectively. It is striking to determine the co-author's percentage contribution at the level of 0.2%, it seems that such a small contribution (1/500!) should not qualify for co-authorship of a scientific paper.

Chapter 1: Glacier hydrology in Svalbard

It is a well-written introduction that effectively acquaints the reader with the discussed topic and the study site. Perhaps it would have been informative to include also a map of bedrock and ice thickness of the investigated glaciers? The meteorological background could be longer - at least up to the year 2020 - which would allow for inferences about further changes in the IDS and subglacial drainage network, especially in the context of the availability of a longer ice velocity measurement series (Błaszczyk et al., 2023). Unfortunately, key references to similar recent studies (e.g., Scholzen et al., 2021) are missing, resulting in unwarranted claims exaggerating the novelty of the presented research.

Chapter 2: Datasets and methods

This chapter provides a detailed description of the data and methods. In my opinion, the most interesting aspect is the description of water pressure measurements in the IDS. The creativity in installing sensors in moulins is noteworthy, and in such a challenging environment most of the instruments successfully recorded water level fluctuations. It's unfortunate that water depth measurements in the moulins were not attempted. This brings also the question to what extent is Crystal Cave representative of the entire drainage network? It is mainly supplied from outside the glacier (Benn et al., 2009) and is located at the confluence with a tributary glacier, in relatively shallow ice. It's a pity that the data series from M3 is so short, as it is the only measurement point in the main trunk of the glacier where one can hope for a direct connection to the main subglacial system.

I am a bit sceptical that the accuracy of the subglacial topography raster at a resolution of 100x100 m corresponds to a few meters. I wonder, on what basis was this assumption made, given the uneven spatial distribution of GPR profiles (Lapazaran et al., 2016)? What was the rationale for not choosing the bedrock geometry data of (Fürst et al., 2018)? Regarding the determination of the supraglacial drainage network, why wasn't DEM used for this purpose, similarly to Scholzen et al. (2021)?

I noticed that older autumn measurements indicated a significantly lower water level than what is observed currently, as it was possible to reach the glacier bed in the moulins. Is there any comment on this? Does it result in increased sliding velocity, or was it perhaps a local effect, and subglacial water pressure didn't actually change significantly?

Chapter 3: Role of discrete water recharge from supraglacial drainage systems in modeling patterns of subglacial conduits in Svalbard glaciers

This chapter is based on Article I (Decaux et al., 2019), in which the doctoral candidate presents the results of considerations regarding the influence of incorporating discrete supraglacial recharge on the IDS. On one hand, the results indicate relative stability in the surface drainage system. On the other hand, they demonstrate how significant the spatial distribution of surface supply is for the modelled distribution of the subglacial drainage system. These are important findings that allow for a broader interpretation of changes observed on other, similar glaciers. However, there is one controversy regarding recharge in the upper reaches of Hansbreen. Recently, numerous crevasses became visible in the accumulation zone, especially between Berrknatten and Sørstrypet. They were not as prominent before, but the diminishing firn layer reduces the stability

of snow bridges and exposes them. Therefore, the assumption of no water recharge in the accumulation zone seems unjustified - the crevasses there can serve as a source of supply for the IDS. Consequently, it appears that not all meltwater will be released from the firn layer at the equilibrium line altitude but can recharge the IDS much higher up glacier. This is particularly significant in the context of Scenario 1 simulation results, which indicate the possibility of subglacial water drainage from the accumulation area towards Kvitungisen (Fig. 6 of Article I) and further to Paierlbreen. What is the doctoral candidate's opinion on this matter? Can the crevasse field in the temperate ice area be considered Water Input Area similar to that just below the equilibrium line? Additionally, I am missing the comparison of these results with those presented in the work by Scholzen et al. (2021).

Chapter 4: Annual cycle of Hansbreen's internal drainage system

The content of this chapter is not based on the Articles I and II and it describes separate findings. It presents mainly theoretical considerations based on a spatially and temporally limited dataset regarding the connections between the englacial and subglacial drainage systems.

The relationships between water pressure fluctuations in the subglacial and englacial systems are not straightforward (Fountain et al., 2005), so it remains an open question to what extent conclusions can be drawn about glacier dynamics related to basal sliding based on fluctuations in water level in the englacial channel, where siphoning may occur, or water may stagnate in abandoned moulins without a connection to the subglacial system (Benn et al., 2009). The Candidate consistently assumes a direct contact of the englacial and subglacial drainage systems, which may not always be the case. Nonetheless, I found this chapter interesting, and it is important to note that it further supports earlier studies that challenge the theory of linked-cavities vs. subglacial channels system (Gulley et al., 2012)

Chapter 5: Internal glacial system linked to glacier dynamics

The last Chapter is partly based on the preprint submitted to GRL (Article II). It investigates the impact of the changes in the internal drainage system on the ice dynamics, with particular emphasis on the winter speed-up events related to warm episodes.

Here, it can be noted that the last of the thesis's objectives was unfortunately formulated, as it corresponded to the content of Article II, while Chapter 5 presents a different interpretation of the results. It appears that the thesis about the glacier's acceleration due to a warm winter event is unjustified – this brief warming event actually caused the glacier to return to its normal regime from an atypical state of slowing down, as the doctoral candidate aptly points out in this chapter.

In my opinion, it is worth considering whether overly far-reaching conclusions are being drawn based on the very episodic behaviour of the glacier in a single season. The 2016/2017 season was atypical (Błaszczyk et al., 2023), and Hansbreen recorded a decadal minimum in ice velocity. If the cause was a warm autumn - a regional forcing - one could expect that other glaciers in Hornsund also slowed down. Was this the case? For example, in the 2018/2019 season, there was also a warm autumn, but the speed of Hansbreen did not decrease; it was significantly higher than in 2016/2017.

General comments

The key findings of this dissertation are related to the stability of the supraglacial drainage network, the importance of discrete water recharge for the modelled subglacial channel structure, the seasonal changes in the efficiency of the IDS, and significant impact of the measured englacial water pressure on the ice flow velocity.

On a multi-decadal timescale, the changes in the supraglacial drainage system have prompted corresponding adjustments in the subglacial drainage system of the investigated glaciers, with no fundamental reorganisation observed in the latter. Additionally, on an annual basis, both glaciers' surface drainage systems consistently maintained their spatial characteristics, implying the presence of similar subglacial drainage systems. In all considered scenarios, the inclusion of discrete water recharge in theoretical subglacial channel modelling leads to more realistic results. Thanks to continuous measurements of englacial channel water fluctuations of Hansbreen, four distinct regimes of IDS functioning were identified, collectively representing a complete hydrological year. During the transition from winter to summer, the subglacial drainage system undergoes a reopening process, transitioning from an inefficient to an efficient state. Similarly, during the summer season, when the subglacial system is already efficient, it undergoes a process to further enhance its efficiency. The results reveal a clear connection between changes in water levels within the englacial channelised system and corresponding variations in glacier velocity. The glacier's dynamic response is influenced by both the volume of water recharge and the effectiveness of the IDS. The hydraulic capacity of the subglacial drainage system is shaped by its water recharge history, with periods of increased hydraulic capacity characterised by englacial water storage events. Remarkably, the subglacial drainage system remains active even during the winter months, with water persisting within the englacial system for extended periods. The transition from winter to summer and significant warm winter events lead to shifts in the efficiency of the subglacial drainage system. The subglacial drainage system exhibits the ability to adapt to the dynamic nature of water recharge during the summer months, allowing the system to adjust its capacity within a day to maintain efficiency throughout the season. These findings highlight the importance of considering a glacier's hydrological history when studying its dynamic responses to external forcing. The subject of the thesis is of high interest, and the presented measurement results and their interpretation will undoubtedly contribute to a better understanding of the connections between the IDS and glacier dynamics. In my opinion, particularly valuable are the acquisition of in-situ data series related to englacial water pressure and the significant effort put into manually mapping the supraglacial drainage network using high-resolution satellite imagery.

Unfortunately, the thesis contains numerous editorial errors and misspellings that lower its perceived value. Moreover, the last goal of the thesis, which is to identify the effect of warm winter events on the IDS and its impact on glacier speed, appears to be unmet. Regrettably, the measurement series are very short, which prevents obtaining strong, conclusive findings. Nevertheless, they open up opportunities for hypothesis formulation and their preliminary verification, which the doctoral candidate successfully exploits. The presented dissertation represents a significant contribution by the doctoral candidate to the research on glacier drainage systems and their impact on glacier dynamics.

Conclusion

This dissertation demonstrates the candidate's ability to pose research questions, select appropriate methods necessary for their resolution, and showcases his overall theoretical knowledge in the field of Earth and environmental sciences. In summary, I hereby issue a **positive opinion** on the doctoral dissertation submitted to me for review by Léo Decaux, and I affirm that it meets the requirements set for doctoral theses in accordance with the Act of March 14, 2003, on academic degrees and the degree of Doctor and the degree of Doctor in the arts. Based on this, I recommend allowing the Candidate to proceed to the public defense of the doctoral thesis.

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