Some comments on the flow velocity and thinning of Svenbreen, Dickson Land, Svalbard

Jakub Małecki

Adam Mickiewicz University, Cryosphere Research Department, ul. Dzięgielowa 27, 61-680, Poznań, Poland

Abstract

In this study a differential GPS survey of flow velocity and surface elevation change of a small glacier Svenbreen, central Svalbard, is presented and discussed. The maximum measured velocity was 3.21 m a^{-1} at 463 m a.s.l., close the theoretical steady-state equilibrium line altitude. After decades of thinning known from earlier research, the glacier surface has been continuing to lower over the analysed time span 2010-2012 by 1.82 m a^{-1} at the front at 185 m a.s.l. and 0.08 m a^{-1} at 541 m a.s.l. Since the glacier dynamics is very low, the study concludes that negative mass balance is the main driver of negative geometry changes and that no new distinct landforms will be formed in the near-future in the glacier forefield.

Key words: glacier flow, glacier dynamics, glacier geometry change, glacial geomorphology

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Introduction and study area

Studying glacier dynamics is an important research task, as it influences many glacier characteristics, *i.e.* glacier geometry, mass balance, thermal structure, hydrology and geomorphological activity. In Svalbard, high Arctic, climate warming since early 20[th] century has been causing strong glacier-wide thinning of small local ice masses (Nordli et al. 2014, Nuth et al. 2007, Moholdt et al. 2010). In case of larger surge-type glaciers, negative changes were restricted only to their lower zones, while their upper reaches have been showing a considerable long-term elevation increase, followed by rapid mass transfer from higher to lower elevations (*e.g.* Sund et al. 2009). Glacier surface fluctuations in Svalbard are therefore partly caused by negative mass balance and partly by changes in motion dynamics. To properly interpret fluctuations of glacier geometry, knowledge of both these elements is essential (Hagen et al. 2005).

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[*]Corresponding author: Jakub Małecki <*malecki.jk@gmail.com*>

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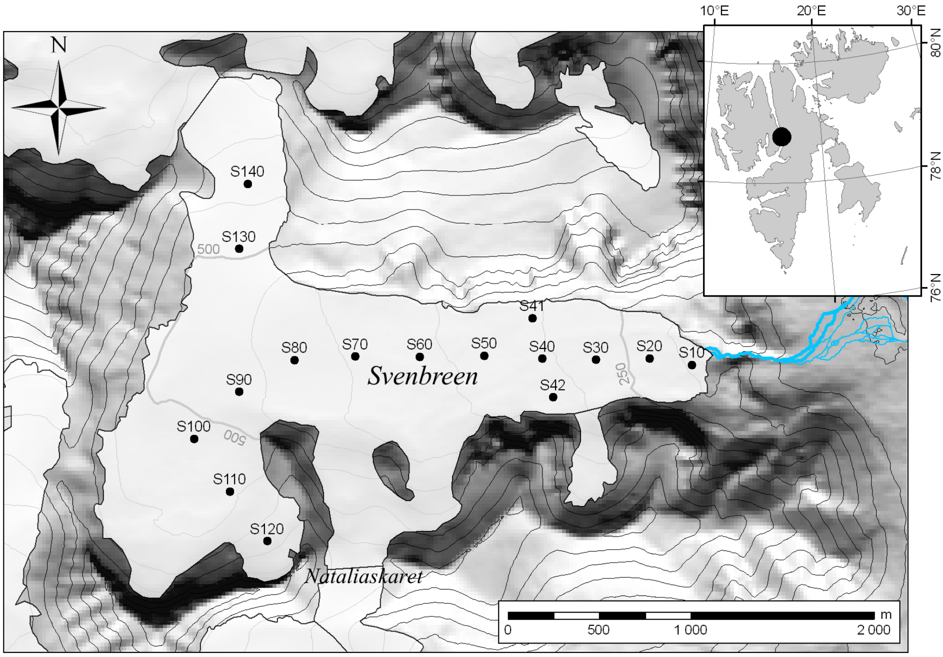

Fig. 1. Location of Svenbreen in Svalbard (upper-right inset) and ablation stake network on the glacier. Contours of 250 and 500 m a.s.l. are bold. Contour interval is 50 m (2009 geometry after Strzelecki 2013).

In Dickson Land in Spitsbergen, the largest island of Svalbard, glaciers have been showing average thinning at a rates from 0.4 to 0.8 m a^{-1} in the period 1960-2009, as measured with use of topographic data (Małecki 2013a, b; Małecki et al. 2013). One of the previously investigated glaciers, Svenbreen (ID 14512 in Hagen et al. 1993), has been an object of detailed glaciological fieldworks (Fig. 1). Svenbreen is a small (3.7 km^2) land-terminating valley glacier spanning from 180 to ca. 750 m a.s.l., with median elevation of 470 m a.s.l. Its theoretical steady-state equilibrium line altitude (ELA) is at about 420 m a.s.l., if zero-balance accumulation area ratio is assumed as 0.6. Svenbreen tongue is oriented towards east, while its accumulation zone is generally exposed towards north, with a minor patch of southern aspect. Glacier surface is even and poorly inclined (10° on average). The only exception are small tributary ice streams, flowing steeply from a mountain pass, given unofficial name *Nataliaskaret*. Svenbreen has been classified as polythermal by Małecki (2013a), with probable temperate ice-bedrock contact and margins frozen to the bed. The glacier is not known to surge in the past.

In this paper, flow velocity of Svenbreen is studied at several points on the glacier surface with use of differential GPS (DGPS). The aim of this survey is to investigate whether its present-day dynamics may have a significant impact on the observed surface elevation changes and on the decreasing geomorphological activity of the snout.

Methods

DGPS surveys on Svenbreen were carried out on 27/07/2010 and 23/07/2012 with Leica equipment in order to measure location of ablation stakes and their displacement. Base station was installed on a stable ground close to the front of Svenbreen, while the actual surface was measured by placing a rover antenna into the snow, thus neglecting the snow surface. Post-processing of the data considered adjusting the measured elevations by introducing proper corrections for local geopotential. It must be underlined that in order to compute differences in surface elevation at each stake between the two years, a downglacier stake motion must have been considered. Therefore, horizontal stake displacement ($U_{2010\text{-}2012}$) and surface slope along the motion vector must have been included in computations of the real stake elevation change, $dh_{2010\text{-}2012}$.

Due to unusually snowy conditions during the 2012 survey, some of the stakes were buried under the snow. In effect, $U_{2010\text{-}2012}$ is available only for 9 stakes and $dh_{2010\text{-}2012}$ for 8 points along the main flowline. Apart from the measurement itself, accuracy of GPS stake survey depended on several other factors. Among the most important were precision of installation of a base station above a fixed point with known coordinates (assumed accuracy ± 0.01 m) and re-measuring exactly the same point on ice as in the earlier survey (assumed accuracy of rover antenna placement is here ± 0.02 m). Precision of single GPS measurement with available equipment was on average ±0.05 m. For the purpose of this study, a conservative overall error for stake coordinates has been set as ± 0.1 m, propagating to ± 0.14 m for both $U_{2010\text{-}2012}$ and $dh_{2010\text{-}2012}$. In case of annual rates of $U_{2010\text{-}2012}$ and $dh_{2010\text{-}2012}$ the error is twice lower (± 0.07 m), since the data covered two years, and the symbols receive a suffix *dt*, becoming eventually $U/dt_{2010\text{-}2012}$ and $dh/dt_{2010\text{-}2012}$.

Results

Results of the survey show generally low horizontal flow velocity of Svenbreen. Maximum flow speed was measured in the middle zone of the glacier and at the entrance to the cirque (Fig. 2A). Stake S60 has been moving at rate of $U/dt_{2010\text{-}2012}$ = 2.48 m a^{-1}, S90 at $U/dt_{2010\text{-}2012}$ = 3.21 m a^{-1} and S100 at $U/dt_{2010\text{-}2012}$ = 2.92 m a^{-1}. The lowest velocity was noted in the front zone. Small displacement of stake S20 gave flow speed of only $U/dt_{2010\text{-}2012}$ = 0.38 m a^{-1}, while S10 was almost stagnant with $U/dt_{2010\text{-}2012}$ = 0.10 m a^{-1}. Motion velocity measured at other sites was 1.05-1.31 m a^{-1} (Table 1).

Flow direction at measured stakes was consistent with the expected flow pattern (Fig. 2B). The only exception was stake S60 moving towards NE, while the other stakes in the ablation zone have shown eastern direction. Surface lowering has been noted at every measured stake (*see* Fig. 3). The greatest thinning occurred at the lowest stake S10 ($dh/dt_{2010\text{-}2012}$ = -1.82 m a^{-1}, Table 1) and gradually decreased with elevation. Stake S60 however has shown similar lowering ($dh/dt_{2010\text{-}2012}$ = -0.73 m a^{-1}) as stake S50 located below ($dh/dt_{2010\text{-}2012}$ = -0.72 m a^{-1}). Zero-elevation change line was probably slightly above S110 (541 m, $dh/dt_{2010\text{-}2012}$ = -0.08 m a^{-1}). The highest stake installed on Svenbreen, S120 at ca. 620 m, has not been found during the later DGPS survey due to thick snow cover, but it could be the only site with positive elevation change in the analysed time span (Fig. 2A).

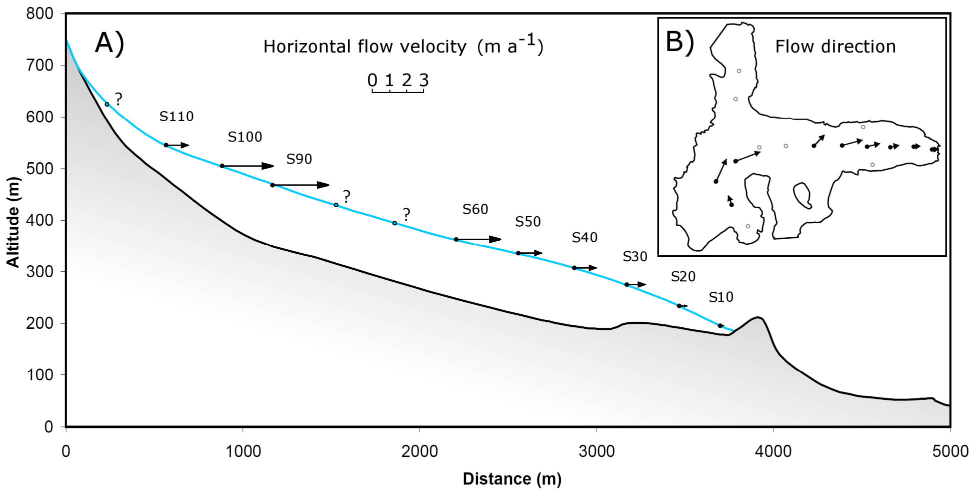

Fig. 2. A - flow velocity of Svenbreen along its longitudinal profile. Bedrock profile after Małecki (2013a); **B** - flow direction at surveyed stakes.

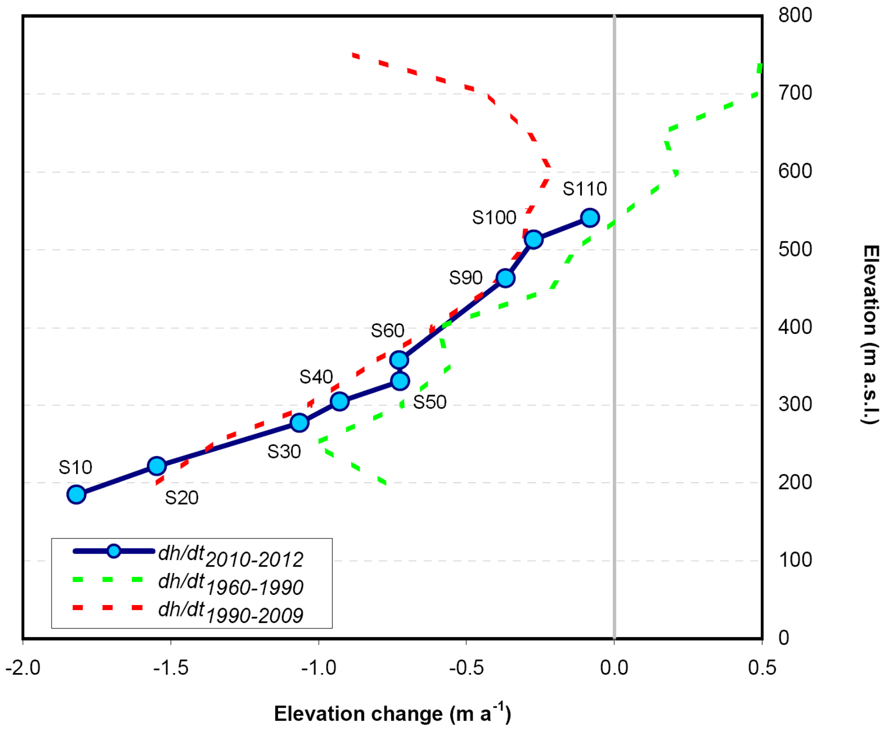

Fig. 3. Annual elevation changes at individual stakes on Svenbreen in the period 2010-2012 (*dh/dt* $_{2010\text{-}2012}$), against centreline elevation changes after Małecki (2013b): in the period 1960-1990 (*dh/dt* $_{1960\text{-}1990}$) and 1990-2009 (*dh/dt* $_{1990\text{-}2009}$).

Stake	2012 elevation (m a.s.l.)	$U/dt_{2010-2012}$ (m a^{-1})	$dh/dt_{2010-2012}$ (m a^{-1})
S10	185	0.10 ± 0.07	-1.82 ± 0.07
S20	222	0.38 ± 0.07	-1.55 ± 0.07
S30	277	1.05 ± 0.07	-1.06 ± 0.07
S40	304	1.24 ± 0.07	-0.93 ± 0.07
S50	331	1.31 ± 0.07	-0.72 ± 0.07
S60	358	2.48 ± 0.07	-0.73 ± 0.07
S90	463	3.21 ± 0.07	-0.37 ± 0.07
S100	513	2.92 ± 0.07	-0.27 ± 0.07
S110	541	1.23 ± 0.07	-0.08 ± 0.07

Table 1. Horizontal flow velocity ($U/dt_{2010-2012}$) and elevation change ($dh/dt_{2010-2012}$) at individual stakes on Svenbreen between 07/2010 and 07/2012.

Discussion

At present Svenbreen flows very slowly, with its maximum velocity of ca. 3 m a^{-1} close to the approximate ELA. Other Svalbard glaciers of its size surveyed in the last 2 decades have very similar average annual flow speed, ranging from less than 1 up to about 5 m a^{-1}, including neighbouring Bertilbreen (*e.g.* Etzelmüller et al. 2000, Hagen et al. 2003, Sund et Eiken 2004, Neumann 2006, Mavlyudov 2010). Larger land-terminating ice masses typically reach higher velocity, with maximum annual speed on the order of 10-15 m a^{-1}, *e.g.* the nearby Hørbyebreen, Ragnarbreen and Ebbabreen, as well as other glaciers in Svalbard (*e.g.* Baranowski 1977, Nutall et Hodgkins 2005, Rachlewicz 2009).

Low dynamics of glaciers in Dickson Land has been previously anticipated by Małecki (2013b) and Małecki et al. (2013), who presented a wider view of glacier elevation changes in the region. These authors assumed that elevation changes of Dickson Land glaciers are mainly driven by their negative mass balance, with glacier dynamics playing negligible role (Nuth et al. 2007, James et al. 2012). This study confirms that dynamics of Svenbreen is very low indeed and that its surface lowering should be primarily explained by enhanced ablation, instead of dynamically-driven vertical surface fluctuations. Because the vast majority of ice masses in Dickson Land is even smaller than Svenbreen, it may be expected that their surface elevation changes are directly related to mass balance as well.

In the period 1960-1990 Svenbreen has been experiencing the slowest mass loss in its region at an average rate of -0.32 m a^{-1}, which increased to -0.61 m a^{-1} in the period 1990-2009 - again the slowest from the nearby glaciers (Małecki 2013b). The presented study provides an evidence of thinning continuation in the recent years. Its $dh/dt_{2010-2012}$ curve agrees very well with those from earlier epochs (Fig. 3), so no recent acceleration of surface lowering is evident, despite the long-term trend of air temperature increase in Svalbard (Nordli et al. 2014). It may be explained by peculiar snow conditions on the glacier during summer seasons of 2010 and 2012, which slowed melting down (Małecki 2013a). The only stake deviating slightly from the general thinning trend 2010-2012 is S60 at 358 m. If its relatively high $dh/dt_{2010\text{-}2012}$ (as for its altitude) is not an artefact resulting from measurement error, then it could be explained by locally enhanced ablation (*e.g.* due to lower albedo or thicker snow cover). Moreover, S60 has been flowing towards NE, whereas the other stakes in the ablation zone have been moving towards E. This motion direction could result either from strong influence of steep *Nataliaskaret* ice streams flowing from S to N, or, again, from a faulty measurement.

The mass loss of Svenbreen observed in the last decades reduced its thickness and likely temperate ice extent considerably. According to Glen's flow law, Svenbreen must have been therefore flowing at a significantly faster rate in the past than it is at present, implying greater dynamics of sediment transport and relief remodelling in the 19th and 20th century. The earliest observations of the glacier by Slater (1925) revealed a completely different character of the glacier than it is today. In 1920's the glacier front has been surpassing the riegel (compare bedrock profile from Fig. 2), steeply flowing downwards to the present moraine zone. The front zone was covered with a dense network of active thrust planes, containing large amounts of sediments, which are lacking at the contemporary front.

In response to a warming climate, since early-20th century Svenbreen has been continuously retreating (Rachlewicz et al. 2007), producing a 1.5 km long marginal zone. It was generally formed until 1960 during rapid disintegration of the snout, with later remodelling by melting of moraine ice-cores and action of proglacial waters. From the north, south and east the moraine zone is closed by huge terminal and lateral moraines, marking the maximum Little Ice Age extent of the glacier. Inside of these boundaries three distinct landforms dominate: a complex of ice-cored hummocky moraine with multiple kettles, an inner outwash plain and washed-out remnants of an esker of uncertain origin (Karczewski et Kłysz 1994, Małecki 2013a).

Diversity of the moraine zone stays in contrast to the present-day front of Svenbreen, which is almost inactive. Formation of new landforms at the actual front is vastly limited: melting ice accumulates a thin cover of supraglacial deposits as a ground moraine in the northern part of the snout, while in its central zone a small medial moraine produces a 0.5 m high longitudinal ridge composed of ice and angular unsorted deposits. The near-front forefield lacks any other distinct landforms, what may be attributed to stagnant Svenbreen front.

Conclusions

The motion dynamics of Svenbreen are very low, with maximum annual flow velocity of 3.21 m a^{-1}. It suggests that surface elevation changes of the glacier may be almost completely attributed to its mass balance. Surface lowering of the glacier has been continuing in the period 2010-2012 and was the greatest at the front with 1.82 m a^{-1} and only 0.08 m a^{-1} at 541 m. Due to negative changes in glacier thickness, length and velocity, the Svenbreen forefield has been shaped with a gradually decreasing diversity. Present-day physical properties of the glacier are insufficient to maintain high geomorphological activity of the snout, so no new distinct landforms are to be found in the closest front proximity.

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