Numerical modelling of the fluctuations of Qaanaaq Glacier in northwestern Greenland from 1985 to 2022

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Glaciers and ice caps in northwestern Greenland are rapidly losing mass (Khan et al., 2022). Mass loss of the glaciers affects the ice flow regime, and in turn flow changes affect glacier mass loss. Therefore, we need to observe ice flow velocity for a long period to understand its influence on the mass changes of glaciers and ice caps. To investigate glacier mass loss and dynamics, we have performed field observations at Qaanaaq Glacier, an outlet glacier of Qaanaaq Ice Cap in northwestern Greenland, since 2012. Satellite data analysis showed a surface elevation change of Qaanaaq Ice Cap as −1.8 ± 0.1 m a^{-1} during 2006–2010, which was more rapid than other ice caps in the region (Saito et al., 2016). To better understand thr rapid mass loss and changes in ice dynamics, we developed a numerical glacier model of Qaanaaq Glacier. In this study, we present glacier changes from 1985 to 2022 computed based on observational data since 2012.

Qaanaaq Ice Cap is located in northwestern Greenland (77°28'N,69°14'W) and its surface area is 289 km^2. Qaanaaq Glacier, our study site, is one of the outlet glaciers on the southern side of the ice cap. Ice flow velocity and surface mass balance have been observed from 2012 to 2022 at six sites on the glacier at elevations between 243 and 968 m a.s.l. (● in Fig. 1). Surface and basal elevations were measured by GPS and ice radar on July 26–30, 2012 and August 3, 2022 (dashed line in Fig. 1).

A two-dimensional numerical model was constructed to reproduce the surface elevation change and front position change along the central flow line of the glacier (dashed line in Figure 1). The model calculates the surface elevation and terminal location every 0.5 year with the surface mass balance prescribed for each year. The annual mass balance was estimated from the correlation between positive degree day and observed surface mass balance. and Ice flow velocity was calculated by solving Stokes equations with finite-element method (Sugiyama et al., 2014). The glacier front retreats when the calculated surface elevation is below the basal elevation. The initial surface elevation was obtained from a digital elevation model in 1985 (Korsgaad et al., 2016) and the basal elevation observed in 2012 was used for the basal boundary. The experimental period was carried out from 1985 to 2022. The coefficients for ice deformation, geothermal heat flux, and friction from the sidewalls were optimized to reproduce ice flow velocity observed in 2012/2013.

Numerical experiments showed that the average change in surface elevation over the period 1985–2022 was −34 m. The observed change over the same period was −26 m. The modelled elevation change was faster than the observation by 31 % (Fig. 2). The calculated retreat distance was 828 m, while the glacier retreated by 613 m during the period. Considering the complex behavior of the sediment-covered glacier terminus, the numerical model reasonably well reproduced the retreat of the glacier. Surface elevation changes between 1995–2005 and 2005–2015 were −0.38 m a^{-1} and −0.79 m a^{-1}, respectively, showing a two-fold acceleratioln in the thinning. The surface mass balances averaged for the periods 1995–2005 and 2005–2015 were −0.84 m a^{-1} and −1.33 m a^{-1}, which were counteracted by the emergence velocities of 0.40 m a^{-1} and 0.41 m a^{-1} (Fig. 3). From the experimental results, we conclude that the surface elevation change accelerated because of the increasingly negative surface mass balance.

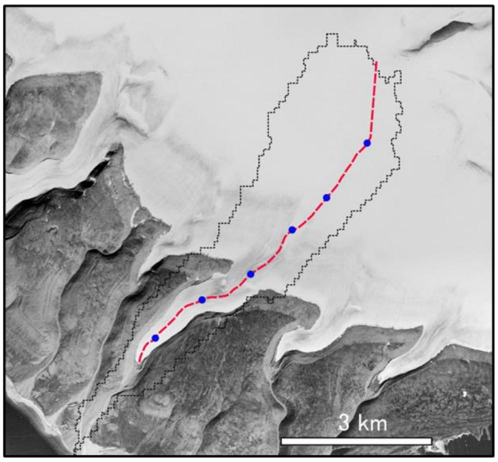

Figure 1. Aerial photograph of Qaanaaq Glacier taken in 1985 (Korsgaad et al., 2016). Indicated on the image are the Qaanaaq Glacier catchment (dotted line), ice flow velocity and surface mass balance observation sites (●), and the profile of the basal and surface elevation measurement (dashed line).

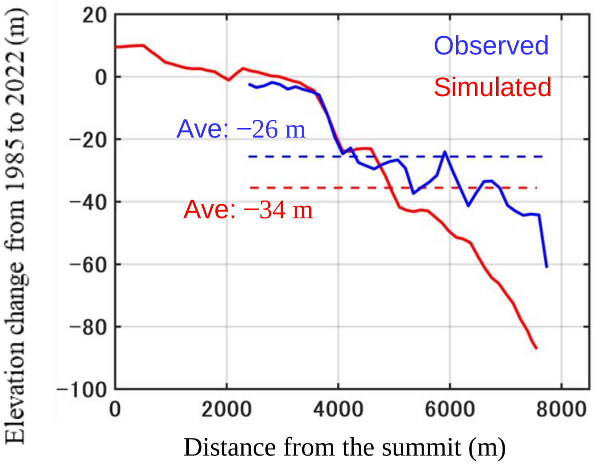

Figure 2. Calculated (red) and observed (blue) surface elevation change from 1985 to 2022. X-axis is the distance from the top of the glacier. Dashed lines are averages for the region x = 2000–8000 m.

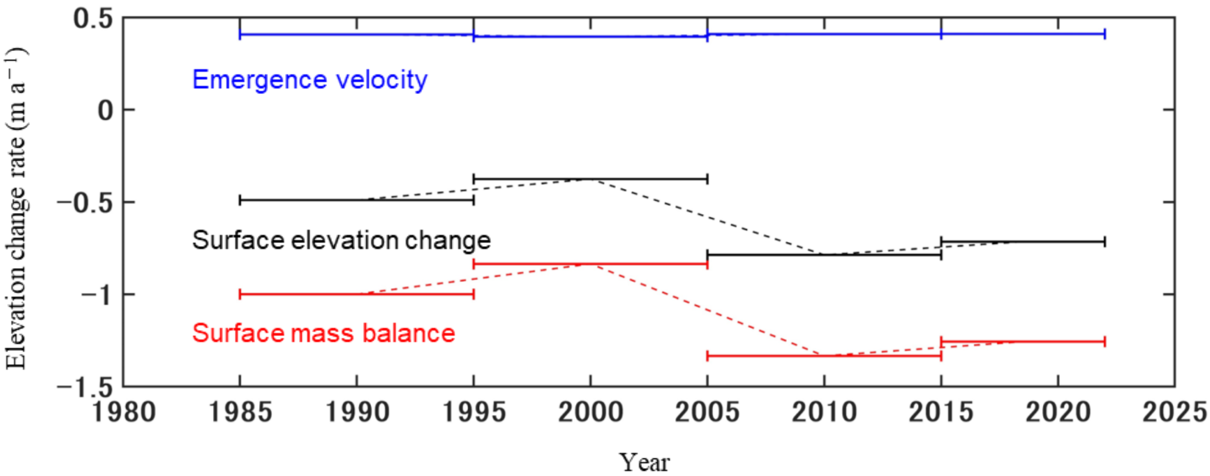

Figure 3. The rates of surface elevation change (black), surface mass balance (red), and emergence velocity (blue) averaged in each time period.

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