学 位 論 文 審 査 の 要 旨

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学 位 論 文 題 名

Changes in marine-terminating outlet glaciers
in northwestern Greenland from remote sensing
（リモートセンシングを用いた
グリーンランド北西部における溢流氷河の変動に関する研究）

Mass loss from the Greenland ice sheet has accelerated over the past two decades. This change is due to melt increase in the ablation area and accelerated ice discharge from marine-terminating outlet glaciers, which are linked to the warming climate. Understanding the glacier changes under the rapidly changing Arctic climate is crucial for constraining the contribution of the Greenland ice sheet to sea-level rise. To study glacier changes over a broad area on a decadal scale, satellite remote sensing is a suitable and commonly employed approach. The goal of this study is to use multi-source remote sensing datasets to improve our knowledge of glacier changes in the Prudhoe Land region in northwestern Greenland over the last four decades. To achieve these goals, I therefore monitored elevation changes and supraglacial lake changes in this study.

I used digital elevation models derived from satellite images and aerial photographs to quantify the mass loss of 16 outlet glaciers in the study area from surface elevation change from 1985 to 2018. The mean rate of the surface elevation change over the studied glaciers was -0.55 ± 0.24 m a^{-1} for 1985–2018. Detailed analysis of the data revealed a clear shift from slight thickening (0.14 ± 0.17 m a^{-1}) in 1985–2001 to rapid thinning (-1.31 ± 0.20 m a^{-1}) in 2001–2018. Glaciers terminating in shallower fjords directly connected to Baffin Bay showed a thinning rate 40% lower than those in the Inglefield Bredning region. Among the glaciers studied, Tracy and Farquhar Glaciers located in Inglefield Bredning thinned most rapidly, at a rate exceeding -9 m a^{-1} in the period 2001–2018. Since the late 1990s, warming trends were observed in both atmospheric (0.09°C a^{-1} in 1996–2009) and ocean temperatures (0.18°C a^{-1} in

1996–2012), which are the most likely triggers of the regime shift at around 2000. In addition to the climatic influence, ice speed acceleration might have enhanced the observed surface lowering as a result of dynamic thinning. The glacier change showed a substantially large spatial heterogeneity, which is attributed to the glacier geometry and fjord bathymetry. Glaciers terminating in deep fjords have lost greater mass because they are subjected to greater acceleration and are more affected by ocean warming.

To monitor the supraglacial lake evolution, I implemented a supervised machine learning methodology in Google Earth Engine for automatically mapping lakes on Tracy and Heilprin Glaciers between 2014 and 2021. Although the basin areas of Heilprin and Tracy glaciers are similar (654 km^2 and 540 km^2), the maximum lake surface area on Heilprin (22.84 km^2) was three times greater than that on Tracy (7.60 km^2). Lakes began formation in early June, which was followed by substantial expansion from middle of June and maximum area in August. The area peaked in different timing every year, depending on meteorological conditions. In 2016, 2019, and 2020, lake area reached peak values between late June and beginning of July. In 2017 and 2018, however, the peaks were observed later in late July because of cold summer temperature. To find the controlling factors for the lake evolution, we compared our lake area dataset with glacier surface topography, ice speed, air temperature, modelled surface mass balance and snowmelt. The result revealed that most of the lakes developed within the surface depressions and preferentially located away from steep slopes and fast-flow areas. Supraglacial lakes spread from lower to higher elevations as the temperature reaches above-freezing. Air temperature and melt rate do not necessarily correlate with lake coverage particularly below the elevation of 800 m, because lakewater drains through moulins or fractures as the melt season progressed. The maximum inland expansion of supraglacial lakes depends on the equilibrium line altitude, above which, no lake develops because snow absorbs meltwater.

This study clearly showed a rapid increase in the glacier mass loss in the 21st century, and provided high spatial and temporal resolution records of supraglacial lake evolution in northwestern Greenland. Together with the drivers for the elevation change and lake evolution identified by the analysis, the study results help our understanding of ongoing glacier changes as well as the future evolution of the Greenland ice sheet.