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Ph. D. Dissertation Summary
博士論文要約

**Glacial meltwater distribution and its variability
in the northwestern Greenlandic fjord**

(グリーンランド北西フィヨルドにおける
氷河流出水の分布とその変動特性)

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In recent years, glacial meltwater discharge from Greenland into the surrounding ocean has increased, affecting recent rapid ice mass loss. Meltwater discharge significantly affects fjord water circulation, material transport and biological productivity. Despite its importance in the understanding of impact of glacial meltwater on the fjord environment, the three dimensional distribution of turbid glacial meltwater and its variability are incompletely understood. Because meltwater transports sediments from land and spreads as high turbidity water adjacent to the ice sheet, the distribution of glacial meltwater can be visualized by turbidity. Although remote sensing data analyses are suitable for understanding the visualized horizontal distribution at the ocean surface in the broader area, the vertical distribution cannot be captured by this method. Moreover, because the marine-terminating glacier discharges subglacial meltwater into the ocean at several hundred meters below sea level, turbid subglacial meltwater plume doesn't necessarily reach the fjord surface. Therefore, to understand the whole picture of the three dimensional distribution of glacial meltwater, we need to investigate not only the horizontal distribution of glacial meltwater at the surface but also the vertical distribution. In-situ observations and numerical experiments are useful for monitoring the vertical distribution and its formation process. From the above, this study focuses on the northwestern part of Greenland that ice mass loss is increasing and aims to investigate the three dimensional distribution of turbid glacial meltwater in the fjord and the controlling factor of its variability, based on remote sensing data analyses, in-situ observations and numerical experiments.

First, remote sensing data analyses were carried out to quantify the spatial and temporal variations in high turbidity surface water off the Thule region. The high turbidity area was distributed near the front of outlet glaciers that discharge glacial meltwater from

the ice sheet and ice caps. The turbid water area increased in mid-July and its annual maximum extent varied greatly from year to year ($1340 \pm 600 \text{ km}^2$). These year-to-year variations in annual maximum extent of the high turbidity area in summer were positively correlated with air temperature measured at Thule ($R > 0.6$, $p < 0.05$); on the other hand, their correlation with wind stress was poor ($|R| < 0.4$, $p > 0.3$). These results suggest that the extent of observed turbid water is largely influenced by the discharge of turbid glacial meltwater rather than by re-suspension of sediments driven by wind mixing. This relationship between the turbidity area and discharge is likely applicable to not only off the Thule region but also the regions that consist of the relatively large shelf area and glaciers located near the open ocean/fjord off the western Greenland coast. Assuming a linear relationship between the high turbidity area and summer temperature, annual maximum extent increases under the influence of increasing glacial meltwater discharge.

Second, in-situ observations and numerical experiments were performed in the Bowdoin Fjord to quantify the vertical distribution of subglacial meltwater and reveal its controlling factor. The maximum subglacial meltwater fraction was observed at the subsurface layer (15–40 m depth) near the ice front ($\sim 6.0\%$ in 2014, $\sim 4.0\%$ in 2016). The difference in the subglacial meltwater fraction at the subsurface can be due to the interannual difference in ambient fjord stratification depending on the layer developed (submarine melting layer in 2014, seasonal pycnocline in 2016) and the amount of subglacial discharge. Because of the thicker warm layer attributed to AW, submarine melting layer can develop in 2014. Near the surface (5–15 m depth), turbidity was higher in 2016 than in 2014, consistent with the stronger influence of turbid subglacial meltwater. The numerical model result with 20% larger discharge suggests that the difference near the surface is primarily affected by the increase in discharge. As the amount of meltwater

discharge increases, the outcrop area of turbid subglacial meltwater at the fjord surface can be expected to spread broader with higher subglacial meltwater fraction.

Third, satellite data analyses and numerical experiments were performed in the whole Inglefield Bredning in 2016 to understand the broader behavior of turbid glacial meltwater and link between the Bowdoin Fjord and a broader fjord system. In the Inglefield Bredning fjord system, high turbidity area increased from mid-July to the end of July (2140 km²) and then decreased until mid-August (260 km²). This maximum extent of high turbidity area occurred about 10 days later after the timing of the highest air temperature. This result suggests that the whole sequence of processes, from ice surface melt and subglacial meltwater discharge to spreading of turbid subglacial meltwater over the fjord surface, takes about 10 days. Given the meltwater runoff reach the conduit mouth within a few days, the time scale was roughly consistent with the time scale from the start of subglacial discharge to spreading of meltwater at the fjord surface in the numerical model experiment. The observed high turbidity water can reflect the anticlockwise drift patterns of turbid glacial meltwater, possibly overlaid by the following pattern. The pattern is that meltwater discharges from the glacier that located nearer the mouth of Inglefield Bredning blocked the northward spread of subglacial meltwater from the other glaciers.

From the above, this study indicated that the amount of glacial meltwater discharge and observed fjord stratification can control the horizontal and vertical distributions of turbid glacial meltwater in the northwestern Greenlandic fjord. Based on the relationship the distribution of turbid glacial meltwater and the amount of glacial meltwater discharge, turbid glacial meltwater at the surface can spread broader with higher concentration under the influence of increasing glacial meltwater discharge, as can be inferred from present

and predicted future trends. The results in this study contribute to a better understanding of the impact of glacial meltwater discharge on the fjord environment that is the current important issue. Although observed fjord stratification can affect the glacial meltwater distribution, the detailed long-term (seasonal and interannual) variability in fjord stratification is still unclear. A mooring has been deployed in Bowdoin Fjord since August 2016 to reveal long-term variability of ocean current, temperature and salinity in the deep layer of the fjord, including AW and PW layers. Combining this mooring data and summer CTD data, and performing the numerical experiment based on these observational data are required to assess the long-term formation process of stratified structure and the future changes in glacial meltwater distribution affected by fjord stratification.