Sea Ice Experiment for Examining the Relationship Between Sea Ice Thickness and Its Reflectance

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***Abstract*:** *Due to global warming, the sea ice extent in the polar regions has been dramatically reduced for the past decades. Monitoring the global sea ice extent is becoming increasingly important. Remote sensing is a powerful tool for monitoring the global distribution of sea ice. The optical sensors onboard satellites such as MODIS, VIIRS, and MSI can monitor the detailed distribution of sea ice under clear-sky conditions. One of the interests of optical sensors is to estimate the ice thickness. In this study, the author performed a sea ice experiment in the sea ice area near the Notsuke Peninsula, Hokkaido, Japan in February 2024. The area was covered with sea ice with thicknesses between a few cm to 40cm. The author moved the sea ice area on a small vessel and measured sea ice thickness and reflectance. The result suggested that under the snowless condition, up to 30 cm of ice thickness, the linear relationship between ice thickness and reflectance was confirmed. This suggests the possibility of estimating thin ice thickness with optical sensors onboard satellites. On the other hand, if the ice thickness becomes thicker than 30cm, the reflectance is likely to be saturated, and it becomes difficult to estimate the ice thickness. We also compared the relationship between ice thicknesses and data value of the optical sensor MSI onboard the Sentinel-2 satellite.*

Keywords:optical sensors, Notsuke Peninsula, thin ice, Sentinel-2, MSI

1. Introduction

The latest Summary for Policymakers of the IPCC Report (2023) says that “Human activities, principally through emissions of greenhouse gases, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850-1900 in 2011-2020”. Since sea ice is quite sensitive to global warming, the importance of sea ice monitoring from space is increasing. Under cloud-free conditions, optical sensors onboard satellites such as MODIS, VIIRS, and MSI allow us to monitor sea ice's detailed condition and distribution with a wide field of view. Since ice thickness strongly affects ice heat flux (Maykut, 1978), ice thickness is one of the important parameters in monitoring sea ice. Various studies on estimating ice thickness with optical sensors onboard satellites have been performed in the past, including Allison (1993), Perovich et al. (1982), Grenfell (1983), Mäkynen (2017), and Cho(2011, 2022). Basically, the reflectance of ice increases as the ice thickness increases. However, since the reflectance of sea ice is likely affected by the freezing conditions and snow cover, the relationship between ice thickness and its reflectance (albedo) varies between observations (Allison, 1993). Also, the reflectance of ice would be saturated at a certain thickness and snow cover. In this study, the author performed a sea ice observation experiment at Notsuke Bay, Hokkaido, Japan, in February 2024. In this paper, the author summarizes the result of the experiment including in situ measurement and satellite observation.

2. Test site and used data

The author has selected Notsuke Bay in Hokkaido, Japan as the test site of this study. Notsuke Bay is a shallow bay located in the eastern part of Hokkaido, surrounded by the coastline of Hokkaido and the curving Notsuke Peninsula (see Figure 1). The width of the mouth of the bay is about 4.3km, and the area of the bay is 5700ha. The maximum depth of the bay is 4m, and the depth of most areas is less than 1m (Ministry of Environment, 2021). Since the bay is separated from Nemuro Strait by the Notsuke Peninsula, the bay is likely to be covered with thin ice in wintertime.

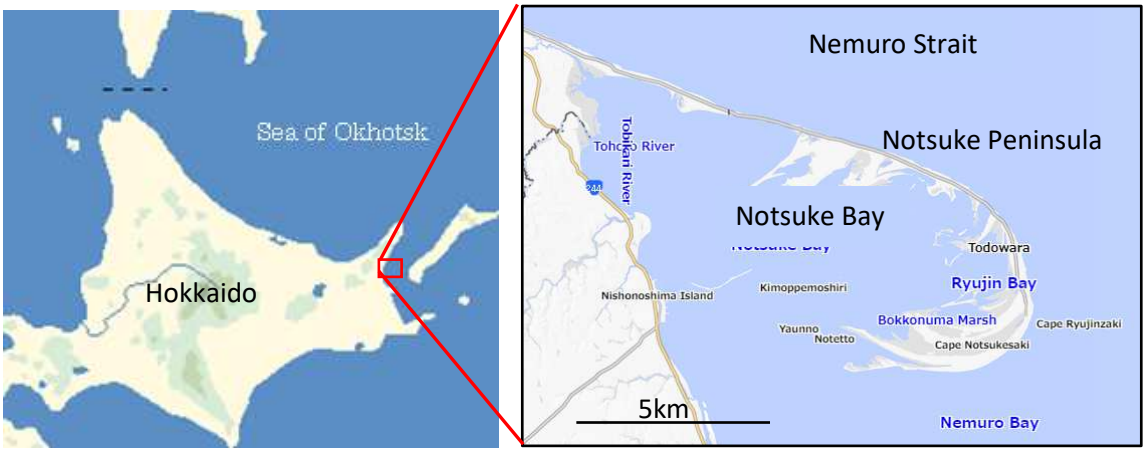


Figure 1. Test site: Notsuke Bay, Hokkaido

In-situ measurements of ice reflectance and thickness were performed at Notsuke Bay. The ASD FieldSpec HandHeld 2 spectrometer (2017) was used for measuring the ice reflectance. The specification of the spectrometer. The ice thickness measurement was performed by using a drill and a measure. The satellite observation was performed by the optical sensor MSI onboard Sentinel-2 satellite. Table 1 shows the specification of MSI for only the bands whose IFOV is 10m.

Table 1. Specifications of MSI

Band	Central Wavelength	IFOV	Swath
2	490nm	10m	290km
3	560nm		
4	665nm		

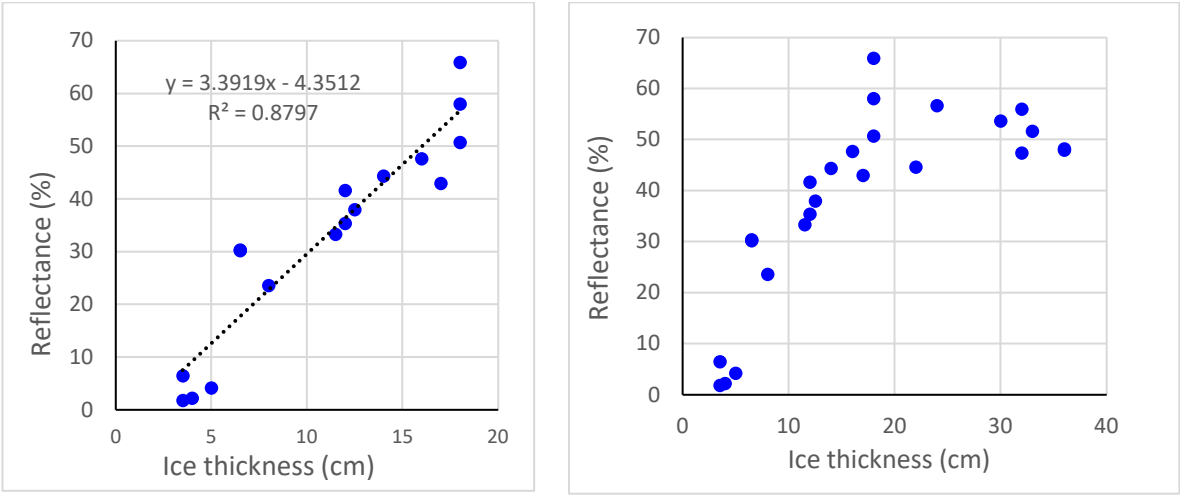
3. Experiment Result

(a)In-situ measurement

A small vessel was used for the measurement. Figure 2 shows the trajectory of the vessel plotted on the MSI image of Notsuke Bay taken on February 25, 2024. Figure 3 shows the relationship between thickness and reflectance of ice. The reflectance at the wavelength of 650nm was used in this study. In Figure 3(a), only the data for ice thickness less than 20cm are plotted. In figure 3(b), all the data are plotted. The result suggests that the relationship is linear when the ice

Figure 2. Trajectory of the vessel at the experiment of 25, February 2024.

thickness is less than 20cm. However, the reflectance is likely to be saturated when ice thickness becomes thicker than 20cm. These results suggest the possibility of estimating thin ice thickness, whose thickness is less than 20cm, and the limitation of estimating ice thickness, whose thickness is thicker than 20cm.

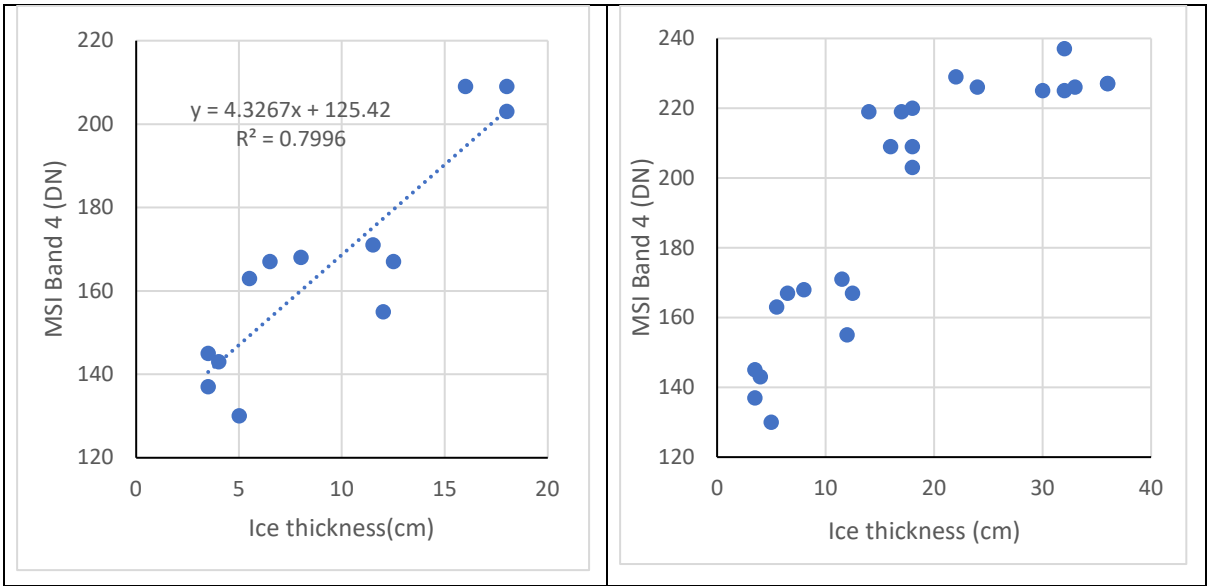


(a) Ice thickness:3-18cm **(b) Ice thickness: 3-36cm**

Figure 4. Relationship between reflectance and thickness of ice

(b) Satellite observation

The ice thickness measurement data were compared with MSI Band 4 digital number (DN), as shown in Figure 5. In Figure 4(a), only the data for ice thickness less than 20cm are plotted. In figure 4(b), all the data are plotted. The result suggests that the relationship is linear when the ice thickness is less than 20cm. However, the MSI band 4 digital number (DN) is likely to be saturated when ice thickness becomes thicker than 20cm. The result was almost the same with the in-situ measurement.



(a) Ice thickness:3-18cm **(b) Ice thickness: 3-36cm**

Figure 4. Relationship between MSI Band 4 data and sea ice thickness

4. Conclusion

In this study, the author has performed a sea ice experiment in the Notsuke Bay of Hokkaido. The main aim of the experiment was to clarify the limitation of ice thickness which can be estimated from reflectance. The result suggested that the relationship between ice thickness and reflectance is linear when the thickness is less than 20cm. However, the reflectance is likely to be saturated when the sea ice glows thicker than 20cm. The result was almost the same for the satellite observation using the Sentinel-2 MSI sensor. The time, snow did not fall for the past few days. The author plans to continue the experiment to evaluate the effect of various conditions including snow cover.

Acknowledgment

This study was supported by JAXA under the framework of the GCOM-W Verification Program and JSPS KAKENHI Grant Number 23K24978. The author would like to thank them for their kind support.

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