THIN ICE THICKNESS MONITORING WITH FORMSAT-2 RSI DATA

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ABSTRACT: Global warming is one of the most serious problems facing mankind in the 21st Century. Sea ice plays an important role in climate variability. Especially, sea ice thickness is one of the key parameters for understanding the heat flux of thin sea ice area. In this study, in situ measurements of thin ice thickness were performed simultaneously with FORMOSAT-2/RSI observation in Saroma Lake and the off the coast of Abashiri Bay, Hokkaido, Japan. The comparison of the in situ measurement of thin ice thickness and FORMOSAT-2/RSI data showed linear relationship between the two. But, on the other hand, ice thicker than 20cm did not show clear relationship of the two. In this study, the authors will discuss about the possibility and limitation of using FORMOSAT-2/RSI data for thin ice thickness monitoring.

1. INTRODUCTION

Sea ice has an important role of reflecting the solar radiation back into space. However, the reduction of ice cover due to the global warming decreases the earth albedo, and increases the amount of solar energy absorption leading to more global warming. This is called "ice albedo feedback". This means that the trend of global warming is likely to be enhanced in sea ice area. Sea ice also has a role of preventing heat exchange between sea and air. Especially, since the heat flux of thin ice is strongly affected by the ice thickness difference (Maykut, 1978), area extraction and thickness estimation of thin sea ice are quite important.

Under the cloud free condition, optical sensors are quite useful for monitoring the detailed condition of sea ice. Various studies on estimating ice thickness with optical sensor AVHRR onboard NOAA satellites have been performed in the past (some examples are Allison, 1993, Perovich et al., 1982, and Grenfell, 1983). Basically, the albedo increases as the ice thickness increases. However, since the albedo of sea ice is likely to be affected by the freezing condition, the relationship between ice thickness and it's albedo changes between different observations (See Figure 1). Moreover, detailed comparison of thin ice thickness with high resolution satellite data were not much done in the past. In this study, authors have performed simultaneous observation of in situ ice thickness measurement and high resolution optical sensor RSI observation from FORMOSAT-2.

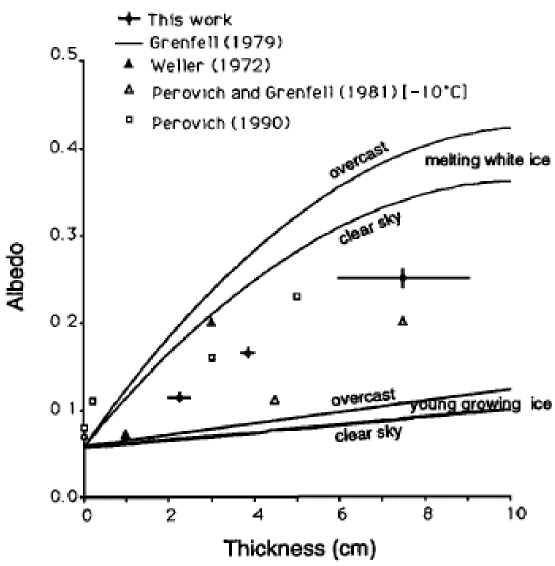


Figure 1. Relationship between ice thickness and albedo. (Allison, 1993)

2. TEST SITES

The Saroma Lake and the off the coast of Abashiri bay of Hokkaido, Japan were selected as the test sites. Figure 2 show the location of the test sites. Saroma Lake is a brackish lake connected to the Sea of Okhotsk with two mouths. The observation experiment was performed during 20 to 26 February, 2011. As for the Saroma Lake, over 80% of the lake was frozen except the two mouths. The drift ice along the coast of Hokkaido were not much at that time, but some were observed off the coast of Abashiri bay.

Figure 2. Locations of the test sites

3. SATELLITE DATA

For evaluating the possibility of estimating thin ice thickness with high resolution optical sensors on board satellites, RSI data of FORMOSAT-2 satellite were used in this study. FORMOSAT-2 is a unique earth observation satellite launched and operated by NSPO of Taiwan. Table 1 shows the specifications of FORMOSAT-2, and Figure 3 shows a part of the orbit map. The orbit of FORMOSAT-2 is fixed and the satellite flies the same orbit every day. It does not cover the whole globe, but can cover certain area every day under the same lighting conditions (sun-synchronous orbit). Fortunately, our test sites in Hokkaido could be covered every day by changing mirror angle of RSI sensor. Table 2 shows the specifications of RSI.

Table 1. Specifications of FORMOSAT-2

Item	Specification
Launch Date	21 May, 2004
Weight	760kg
Size	Hight: 2.4m, Diameter: 1.6m
Orbit	Sun Synchronous Passes through Taiwan twice/day
Altitude	891km
Orbit period	103 minutes
Mission life time	5 years

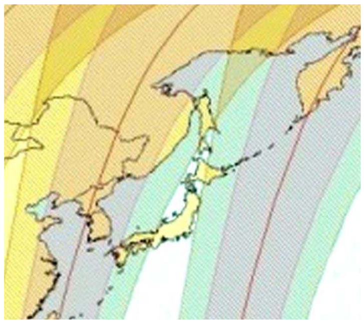
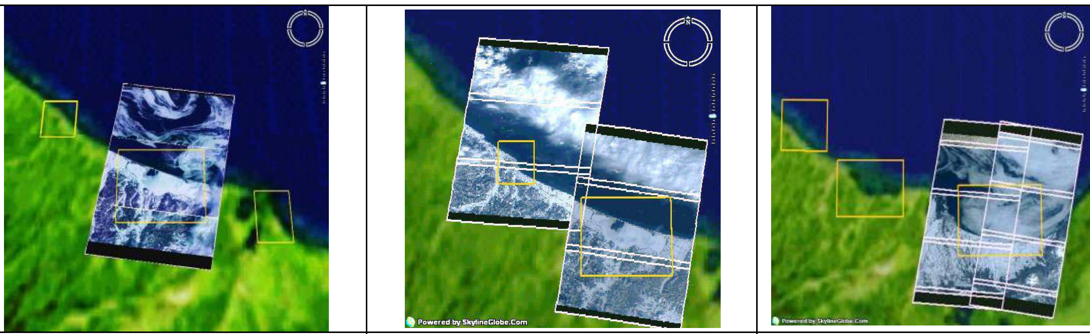


Figure 3. Orbit map of FORMOSAT-2

Table.2 Specifications of RSI

	Band	Wavelength	IFOV	Swath
Pan	Panchromatic	0.45-0.90μm	2m	24km
MS	Blue	0.45-0.52μm	8m	
	Green	0.52-0.60μm		
	Red	0.63-0.69μm		
	Near IR	0.76-0.90μm		

Since the ice condition and distribution change from time to time, simultaneous observation of the satellite and in situ measurement is necessary. Under the cooperation between National Central University and Tokai University, several observations of FORMOSAT-2 over the test sites were performed during 19 to 26 February, 2011. After all, Simultaneous observation data under the cloudless conditions were acquired on February 20 and 26 for the Saroma Lake and on February 22 for the off the coast of Abashiri Bay. Figure 4 show the cloudless browse images of the FORMOSAT-2/RSI which were used in this study.



(a) Saroma Lake 20 February, 2010	(b) Saroma Lake 26 February, 2010	(c) Off the coast of Abashiri Bay 22 February, 2010

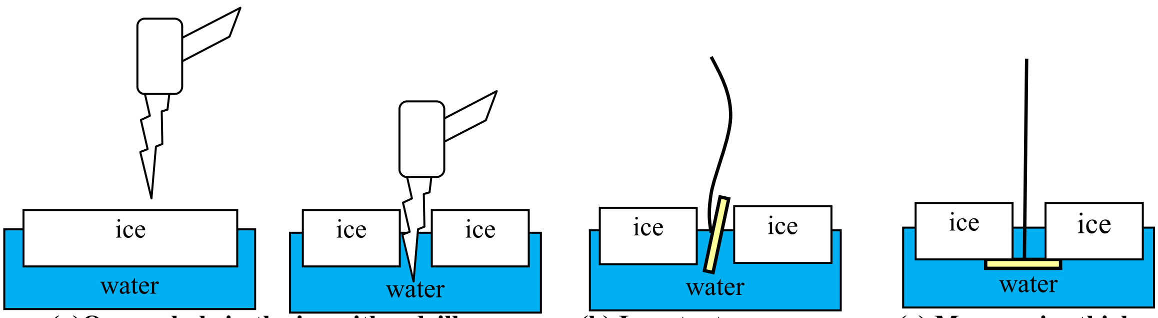
Figure 4. Browse images of the FORMSAT-2/RSI used in this study

4. METHODOLIGY

Synchronizing with FORMOSAT-2 observations, the authors have performed in situ measurement of thin ice thickness in Saroma Lake and at the off the coast of Abashiri Bay. Two methodologies were used for measuring ice thickness as follows.

4.1 Direct Measurement

As for the ice thickness measurement of the Saroma Lake, we used the direct measurement. The procedure of the measurement is shown on Figure 5. The operator makes a small hole in the ice by using a drill (Figure 5(a)). Once the hole is open, the operator inserts a tape measure into the hole (see Figure 5(b)). A bar connected to the forefront of the tape measure act as a prop, and the operator can easily measure the ice thickness with the tape measure (See figure 5(c)). At the time of measurement, most part of the Saroma Lake was frozen. In the thick ice area, we used a snow mobile to move from one place to another. In the marginal thin ice area, we used a small boat for mobile. Figure 6 show the Snapshots of the ice thickness measurement in the Saroma Lake.



(a)Open a hole in the ice with a drill. **(b) Insert a tape measure into the hole.** **(c) Measure ice thickness with the tape measure.**

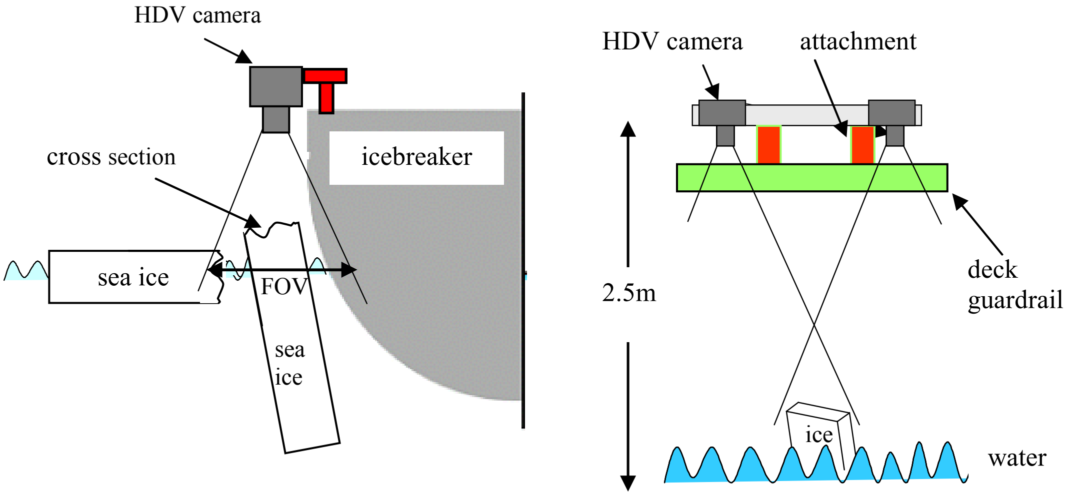
Figure 5. Procedure of direct measurement of ice thickness.

(a) Opening a hole in the thick ice **(b) Opening a hole in the thin ice**

Figure 6. Direct measurement at the Saroma Lake

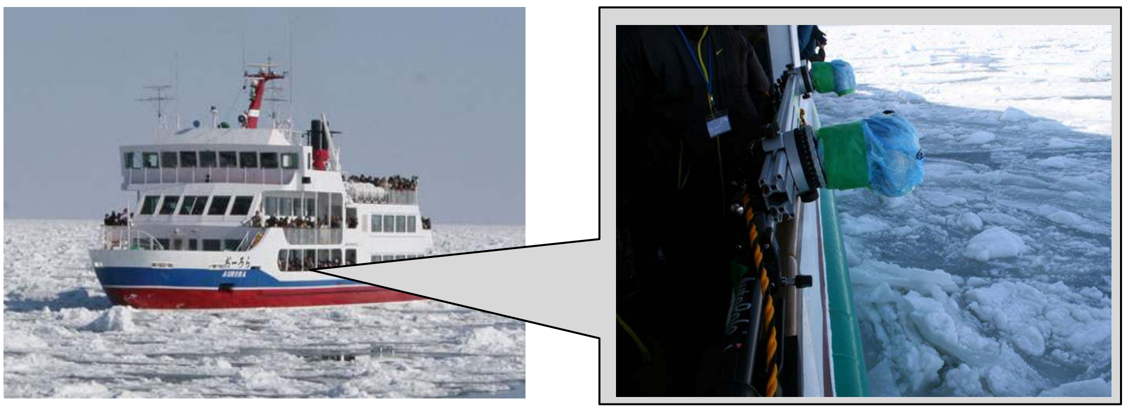
4.2 Indirect Measurement with the Stereo Imaging System

The direct ice thickness measurement on a small boat as described above takes certain time and sometimes quite dangerous. As a result, the area of the measurement will be quite limited. In order to expand the area and speed of measuring ice thickness, the authors have introduced a stereo imaging system using a pair of high definition video (HDV) cameras equipped on an icebreaker (Cho et al. 2010). Two cameras are attached on the deck guardrail of an icebreaker (see Figure 7 and 8). When the icebreaker breaks sea ice, the cross section of the sea ice plate comes above the water and can be captured by the two cameras. The measurement of the ice thickness from stereo pair images were performed using commercial 3D measurement software after the navigation. The HDV camera provides non-interlace 1280x720 pix size images in 60 fps (frames per second). Table 3 shows the specifications of the stereo measurement system. When the target was measured from 2.5m distance, the maximum error of the measurement was 0.7cm for x(horizontal) axis, 0.6cm for y(vertical) axis, and 1.4cm for z(depth) axis.



(a) View from the end of the ship **(b) View from the side of the ship**

Figure 7. The stereo imaging system configuration for ice thickness measurement



(a) Icebreaker Orora **(b) HDV cameras attached on the deck guardrail**

Figure 8. Stereo imaging system equipped on the icebreaker Orora

Table.3 Specification of the stereo measurement system

HDV camera	SANYO Xacti DMX-HD1000
	Pixel number : 1280 x 720 Focus length : f=49.7mm, ISO : 50-800
Imaging specifications	Shutter speed: 1/250-1/500 sec, Flame rate : 60fps Base line : 75cm, distance : 250cm Pixel size : 1.55mm/pixel
Appendix	Adjustable arm (1m)
3D measurement software	Techno Viewer 3D (Techno Vangard)

4.3 Radiance Calculation from Formosat-2 RSI Data

The radiance was calculated from the RSI digital count by the following formula.

Radiance = (Digital Count / Physical Gain) + Physical Bias (1)

Table 4 show the physical gain and physical bias of the RSI data analyzed in this study.

Table 4. The physical gain and physical bias of the RSI data

	Physical Gain				Physical Bias			
Date	B1	B2	B3	B4	B1	B2	B3	B4
2011/2/20	0.726444	0.700531	0.690377	0.816286	0	0	0	0
2011/2/22	0.726444	0.700531	0.690377	1.154581	0	0	0	0
20011/2/26	0.726444	0.700531	0.690377	0.816286	0	0	0	0

5. RESULT

5.1 Direct measurement

In the end of February, the most part of the Saroma Lake were frozen except around the two mouths of the lake as shown in the FORMOSAT-2 RSI image on Figure 9 and 10. We performed ice thickness measurement in two ways. One was thin ice measurement from a small boat at the marginal ice area near the first mouth of the lake (See Figure 9). The other was thicker ice measurement in the middle of the lake ice sheet (See Figure 10). The ice thickness of each point were measured several times and averaged.

Figure 11 shows the relationship between the ice thickness and the radiance derived from RSI band 1 to 4 data measured at the points shown in Figure 9. Though the sample points were limited, the linear relationships were observed between the ice thickness and the radiance acquired by RSI for the thin ice area around the mouth of the lake.

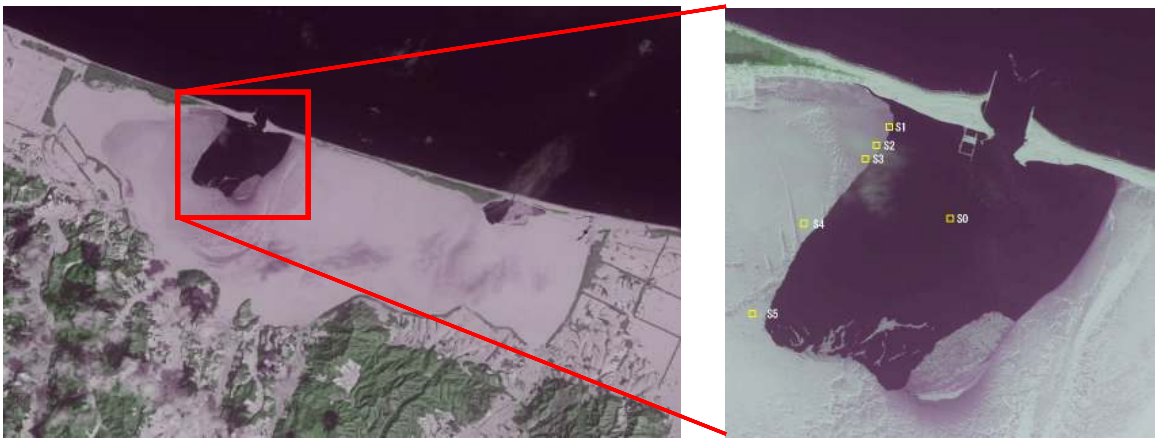


Figure 9. Measurement points plotted on the RSI image (February 26, 2011)
(B,R: Red band, G:Near IR band)

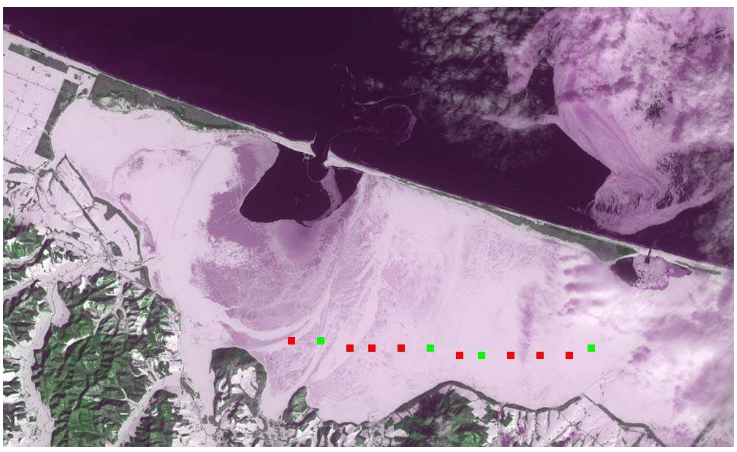
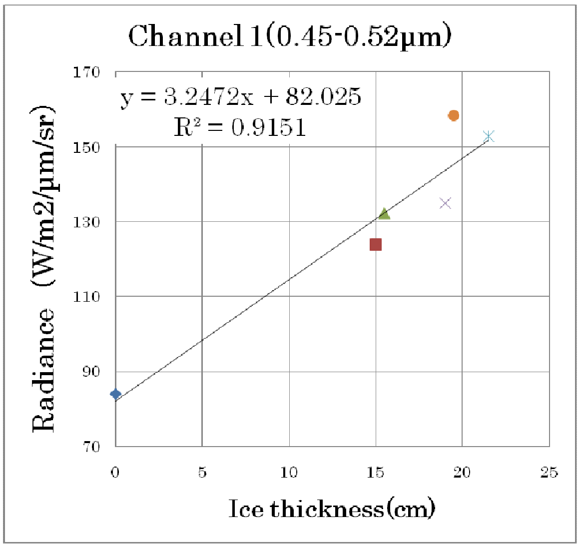
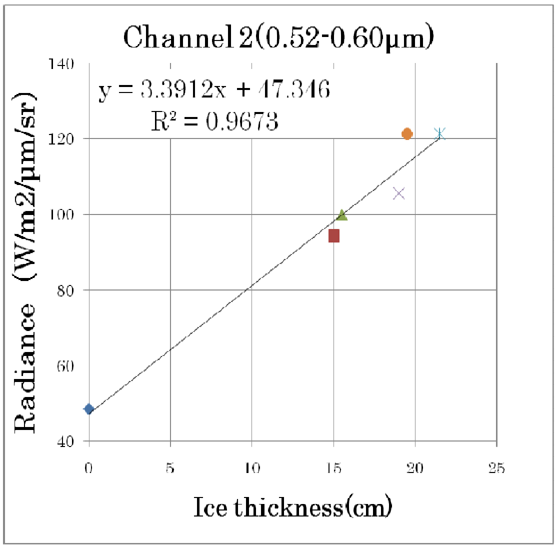


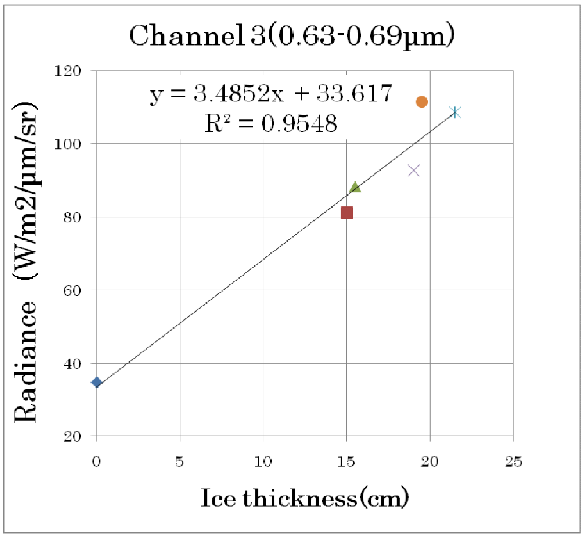
Figure 10. Measurement points plotted on the FORMOSAT-2 RSI image (February 20, 2011)
(B,R: Red band, G:Near IR band)



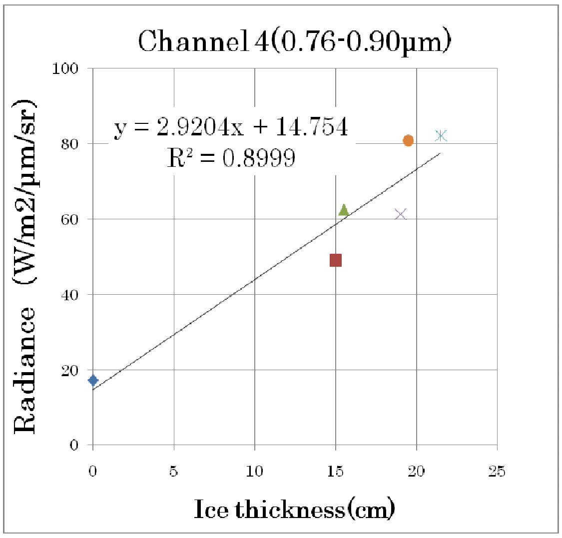
(a)Blue band



(b) Green band



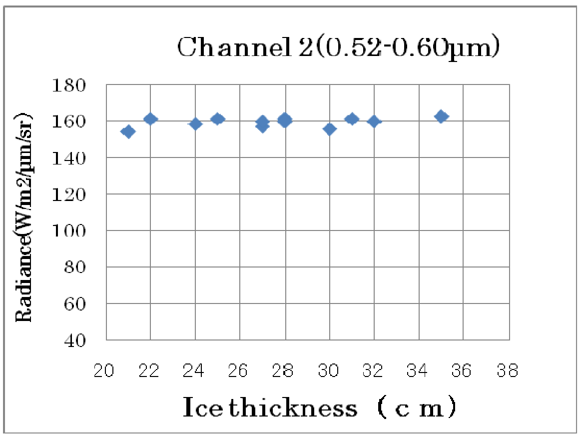
(c) Red band



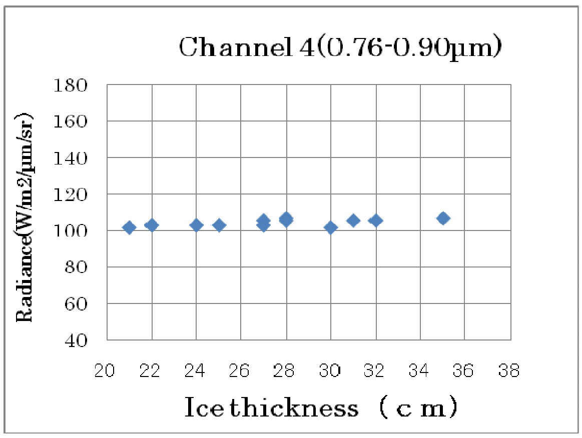
(d) Near IR band

Figure 11. Relationship between thin ice thickness and RSI data (Saroma Lake, 26 February, 2011)

Figure 12 show the relationships between the ice thickness and the radiance derived from RSI band 2 and 4 data for the thicker ice area in the middle of the lake ice sheet. The radiances derived from RSI data were rather stable against the ice thickness changes. This result suggests us that the thickness difference of ice thicker than 20cm may not be able to be detected with RSI data.



(a)Green band



(b) Near IR band

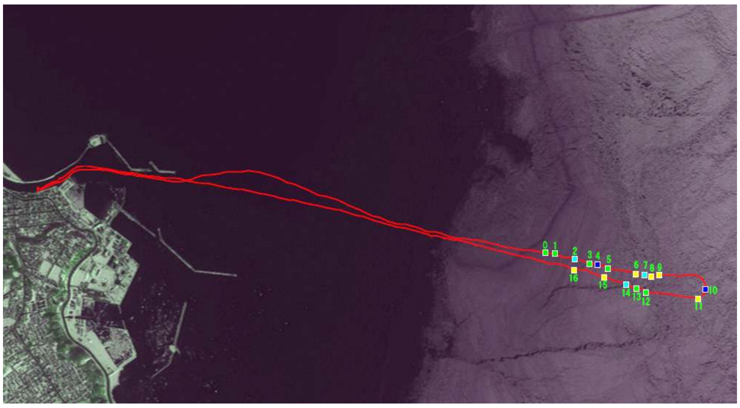
Figure 12. Relationship between thin ice thickness and RSI data (Saroma Lake, 20 February, 2011)

5.2 Indirect Measurement with the Stereo Imaging System

On the February 22, 2011, the simultaneous observations of FORMOSAT-2 and in situ measurement were performed at the drift ice area off the coast of Abashiri Bay. The stereo imaging system equipped on the Icebreaker Orora was used for measuring the ice thickness. Orora is a 491-ton sightseeing icebreaker with a capacity of 450 passengers. Stereo pair images of the cross section of sea ice plates were captured during the cruising, and the ice thickness were estimated from the stereo pair images after the cruising using photogrammetric 3D measurement method. However, due to the high navigation speed of the icebreaker, the auto focus of the cameras did not work so well. We also realized the difficulty of measuring the ice thickness of pancake ice. Since the pancake ice is rather small and round, it was not easy to capture the sharp cross section of the ice with the HDV cameras. Accordingly, not many good stereo pair images of sea ice cross sections were acquired. Figure 13 shows the Orora in the drift ice area, and Figure 14 shows the trajectory of the icebreaker overlaid on the FOROMSAT-2 image. The color boxes show the points where the ice thicknesses were measured from the stereo pair images.

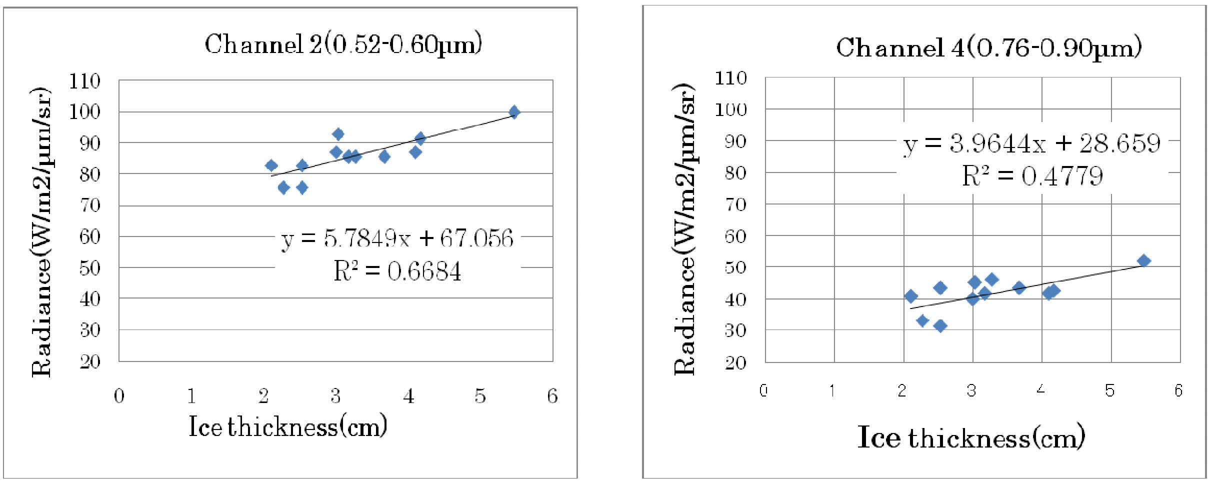
Figure 15 show relationships between the ice thickness derived from stereo images and the radiance derived from RSI band 2 and 4 data. The linear relationship between the ice thickness and the radiance were not so clear as that of the marginal ice area of the Saroma Lake(See Figure 11). If we compare the radiances of same thickness ice for the drift ice at the off the coast of Abashiri Bay with the ice of Saroma Lake, the radiance of the drift ice were much higher. This can be explained as follows. This time, number of stereo pair images which could be used for ice thickness measurement was quite limited. Especially, the thickness measurement of pancake ice covering most of the area was not successful. Accordingly, the ice thicknesses derived by the stereo pair images were not much representing the real ice thicknesses of the sea ice in the area. The measured ice thicknesses were all less than 6 cm, but there were much thicker sea ice in the area. That is why the radiances of the area derived from RSI data were much higher compared with the radiances of the ices in the Saroma Lake for the same ice thicknesses.

Figure 13. Orora in the drift ice area (Feb.22, 2011)



2- 3cm 3 - 4cm 4- 5 cm 5cm-

Figure 14. Trajectories and ponts of sea ice thickness measurement overlaid on RSI image. (Feb.22, 2011)



(a) Green band **(b) Near IR band**

Figure 15. Relationship between thin ice thickness and RSI data(Off the coast of Abashiri Bay, Feb. 22, 2011)

5. CONCLUSION

In this study, in situ measurements of thin ice thickness were performed simultaneously with FORMOSAT-2/RSI observation in Saroma Lake and at the off the coast of Abashiri Bay. The comparison of the thin ice thicknesses and FORMOSAT-2/RSI data showed linear relationship between the two at the marginal ice zone in Saroma Lake where the ice thicknesses were less than 20cm. However, on the other hand, the RSI data were stable at the ice sheet of the lake where the ice thicknesses were over 20cm. This result suggests the possibility and limitation of estimating thin ice thickness from RSI data under the cloudless and snow free condition. The next step of our study is to connect the result with lower resolution optical sensor data such as of MODIS and passive microwave sensor data such as of AMSR-E to improve the total possibility of monitoring thin ice distribution from space. As for the ice thickness measurement from an icebreaker using stereo imaging system, we experienced the difficulty of measuring the thickness of pancake ice under the high navigating speed of the icebreaker. We may need some improvement of the system.

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