Development of sea-ice thickness algorithm from PALSAR data, combined with in-situ observations and other satellite data

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Abstract

In order to estimate the sea-ice thickness distribution in the seasonal ice zone (SIZ), we are developing the algorithm with PALSAR data. As a preliminary step, airborne Polarimetric and Interferometric Synthetic Aperture Radar (Pi-SAR) observation, conducted in the southern Sea of Okhotsk in February 2005, was examined to validate the retrieval of ice thickness distribution from L-band SAR. In conjunction with the airborne SAR observation, in-situ ice thickness and ice-surface roughness measurements were performed in the same area with ship-borne electro-magnetic inductive sounding (EM) and ultra-sonic profiling, respectively. The result indicated the possibility of ice thickness retrieval from the L-band SAR backscattering data. Therefore we planned ice observation in the Sea of Okhotsk in February 2007, coordinated with ALOS orbit path, to apply this to PALSAR data. This paper will present the preliminary result and also introduce our ongoing plan for the Antarctic sea ice.

Keywords: Sea-ice thickness, PALSAR, Seasonal ice zone, Ice surface roughness, ice production

1. INTRODUCTION

Ice thickness distribution is a key parameter to estimate the volume of sea ice and has close relationship with climate change. Particularly in SIZ, where its spatial variation is significantly large, it also provides useful information on the ice growth processes. Moreover, in the coastal region of Antarctica, it controls ice production amount, which is closely related to the formation of Antarctic bottom water. However, still now it is a big issue to obtain this parameter on a global scale. Although satellite images such as SAR, passive microwave sensors, and laser/radar altimeter have been used so far to estimate ice thickness distribution, the feasibility of ice thickness retrieval still needs to be examined due to lack of accurate in-situ ice thickness data. Recently the electro-magnetic induction sounding has enabled us to efficiently obtain the in-situ ice thickness distribution with high accuracy. Regarding the remote sensing tool, L-band SAR data (wavelength = 24cm) seem to be particularly promising in SIZ, where ice freeboard is relatively small and surface roughness is closely related to ice thickness distribution. With this background, the airborne Pi-SAR observation (X- and L-band) was conducted in the southern Sea of Okhotsk, the typical SIZ, in 2005 winter as a preliminary stage of PALSAR. Although the relation between ice thickness and L-band SAR backscatter data has been studied by several researchers (e.g. [1], [2]), many of them concentrated on relatively thin ice (<1m). For thin, not ridged ice, backscatter data are more sensitive to surface brine of ice than roughness, while surface roughness becomes essential for thick ice. Therefore, this experiment provided a good opportunity to clarify the relationship between ice thickness, surface roughness, and SAR backscattering coefficients (BC) quantitatively. The purpose of this paper is to confirm the feasibility of L-band SAR data in estimating ice thickness in the SIZ on the basis of observational results, and then to show the preliminary result applied to ALOS/PALSAR data in the Sea of Okhotsk. Finally, our plan which will be conducted in the Antarctic region will be introduced.

2. Pi-SAR EXPERIMENT

Validation of ice thickness was carried out by comparing the L-band SAR backscattering data along the ship track with in situ measurements of ice thickness and surface roughness. The Pi-SAR observation was conducted in the southern Sea of Okhotsk at noon on February 14 of 2005. Coordinated with this observation, the ground truth data of ice thickness and surface roughness were obtained in the same region using the patrol vessel “SOYA”. The measurement line was about 40 km long, located about 50 km off the coast of Hokkaido (Fig.1).

2.1. Measurements

The air-borne Pi-SAR, developed jointly by the Japan Aerospace Exploration Agency (JAXA) and the National Institute of Information and Communications Technology (NICT), obtained fully polarimetric data both in L- and X-bands.

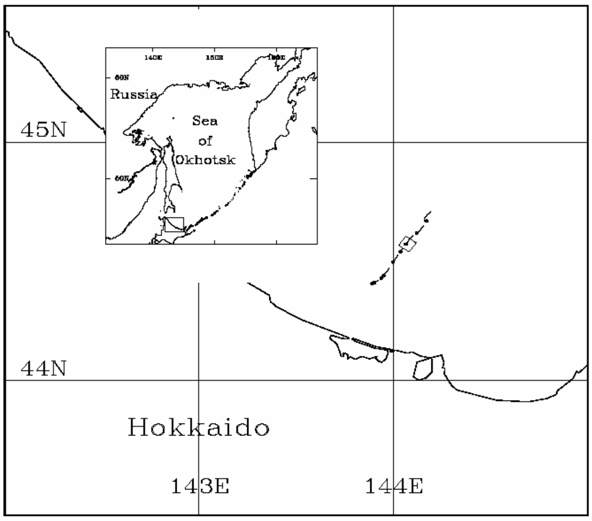

Figure 1. Location map of PI-SAR observation with an inset. A rectangle corresponds to Fig.2 area.

Here we concentrate on L-band polarimetric BC because our main interest is to relate them to ice-surface roughness on the scale of ridging. The original data of 3 m spatial resolution were smoothed spatially with a running mean over 3x3 pixels to reduce the scatter inherent in the data due to small-scale sea-ice heterogeneities and instrument noise.

The ice thickness was monitored with an onboard EM system. The sensor was suspended below a 7-m-long boom extended from the left side of the ship and operated at the heights of about 4 m above ice surface. The footprint of the sensor is estimated to be 5 m. To accurately estimate ice thickness, a new algorithm designed for this region was developed to transform the EM output (conductivity) to ice thickness based on the drilling observation on a specific ice floe of about 2m thick during the cruise [3]. The data sampled at 10 Hz were averaged and recorded on PC every 2 second.

The surface roughness was monitored with a ultra-sonic profiler (KEYENCE UD-390) mounted to the ladder installed at the bow, which measured the height of the sounder above the ice-surface at 10 Hz with the accuracy of 1%. The sounding direction was kept right beneath the sensor using a gimbaling system. To reduce the noise, the profiler data were averaged for 1.3 second (approximately 7 m) and then recorded at the interval of 0.1 second.

2.2. Method of Analysis

To estimate surface roughness from the sonic profiler data, it is essential to remove the effect of the ship motion. For this purpose, we adopted a three-step approach, basically following the method developed by [4]. In the first step, the variability due to ship motion was extracted with a low-pass-filter. Since it was shown that the energy spectrum of rolling and pitching motion appears at 9 and 6 seconds, respectively, and the period of up-and-down motion associated with buoyant force is estimated to be 3.8 second, we adopted the Lanczos-cosine filter whose cut-off period is 2 second. This period corresponds to approximately 10 m. Since the horizontal scale of surface roughness was mostly less than 10m, this filtering appears to work effectively except for large ridged area. The second step is to obtain the sea levels for each profiling data. For this purpose, a standard deviation (sd) of the difference from the filtered curve was calculated for ±2 seconds of each data which contain 41 data. Here the point is that the upper data from the filtered curve were neglected and only the lower data were used for the calculation. The time series of sd were also low pass filtered in the same way. As a final step, the surface roughness data were obtained by subtracting the original profiling data from the calculated sea levels. The obtained values of surface roughness were checked by the front view images which were recorded with a video camera at the ship mast during the cruise. When the roughness data showed unrealistic values, they were excluded. The accuracy is estimated to be about 3 cm since the surface roughness over the completely flat nilas area was 1.4 cm.

Since there is a few hours time lag between the ship-based measurements and airborne observation, it is hard to directly compare the data point by point. Even so, the fact that the surrounding ice conditions did not change substantially allowed us to validate the data for nearby undisturbed area. To do this, the pixels on both side lines 200 m away from the track were taken for averaging. The lines were selected so that the ice conditions were almost the same, and segmented at 1 km interval. Then the averages of BC data along these segments were compared with ship-based ice thickness and surface roughness. Here it should be noted that the location of the ship track was determined by a sequential range of high backscattering values because the ice floes had drifted southward by a few hundreds of meters before airborne measurement. One example is shown in Fig.2.

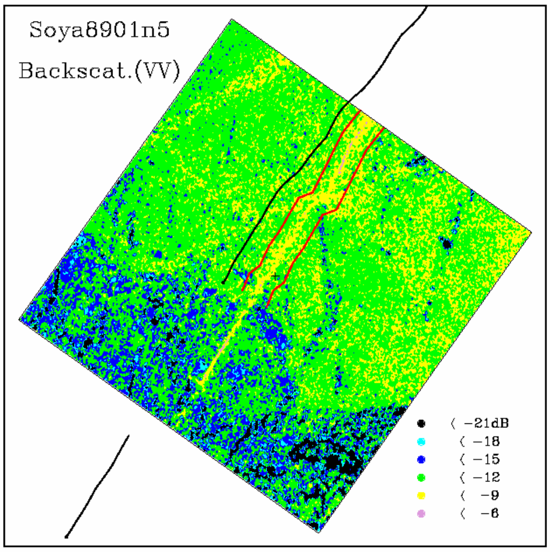

Figure 2. Distribution of backscattering coefficients in the rectangular area of Fig.1. One side is 5 km. Black and red lines denote the GPS record of ship track and line segments for averaging, respectively.

2.3. Results

The number of the segments amounted to 19 in total. The correlation among the three dataset averaged along each segment is shown in Fig.3. Here surface roughness is defined by a standard deviation of surface elevation. First, Fig.3a shows a good correlation between BC and surface roughness, indicating that the former almost represents the degree of the latter. Next, Fig.3b shows that ice thickness is represented well by surface roughness (correlation coefficient = 0.91). This is consistent with the fact that the development of ice thickness especially for thick ice (>0.4m) is controlled by a ridging process in this region [5], and indicates that ridging activities are closely related to the degree of surface roughness. Consequently, ice thickness is well correlated with BC with the rms error of 0.19 m (c.c. = 0.88), as seen in Fig.3c. The result is almost the same for the horizontal data (HH) (c.c. = 0.85). On the other hand, the backscattering ratio defined by VV-HH (dB), which cancels the effect of roughness on backscattering [1], has lower correlation with ice thickness (c.c. = -0.66) than either VV or HH. These results shows that L-band BC data mainly represents the surface roughness and are useful to the retrieval of ice thickness distribution in the SIZ especially for thick ice (>1m) which are accompanied by ridging activities. The ice thickness distribution derived from the regression

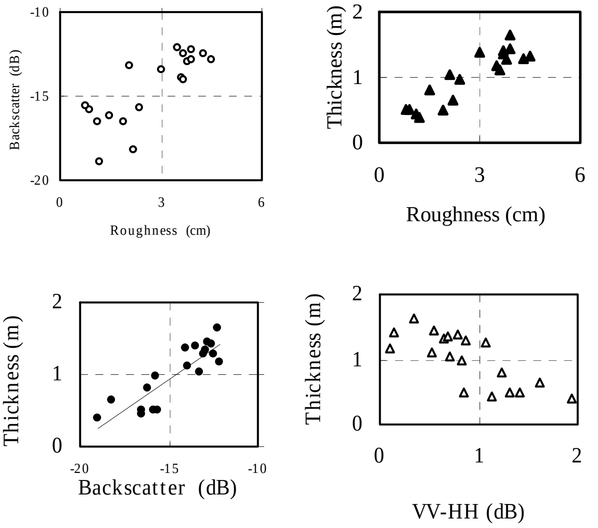

Figure 3. Correlations between

(a) Surface roughness and BC (VV)

(b) Surface roughness and ice thickness

(c) BC (VV) and ice thickness

(d) Backscattering ratio and ice thickness

3. APPLICATION TO PALSAR

In order to apply the above result to PALSAR data, we planned the ship-borne measurement in the sea of Okhotsk with the P/V “SOYA” on 14 February, 2007, coordinated with the ALOS orbit path. We used a laser profiler to monitor the ice surface roughness, and the EM system to monitor the ice thickness distribution. The method of extracting surface roughness is the same as that used for the sonic profiler. The PALSAR image was collected with Scan SAR mode (only HH) to cover the whole area of the southern Sea of Okhotsk. The horizontal resolution is 100m. Although the ship-borne measurement was conducted, the concurrent observation on 14 February was prevented due to bad weather conditions, unfortunately. Therefore, in this paper we compare the result with the PALSAR data using the data obtained on the previous day, as a preliminary step. Figure 4 shows the BC distribution on 14 February. The correlations with ice thickness are depicted for surface roughness (Fig. 5a) and for BC (Fig. 5b). Relatively good correlation between ice thickness and surface roughness can be found for the cases where mean ice thickness has almost linear relation with ice thickness s.d. (closed circle), while there is no significant correlation between BC and ice thickness, irrespective of the cases. This indicates that ice thickness is represented well by surface roughness when it is controlled by ridging processes. No correlation in Fig.5b may be attributed to the significant daily change of ice conditions, assuming that ice thickness distribution is correlated with BC. In any way, further examination is needed.

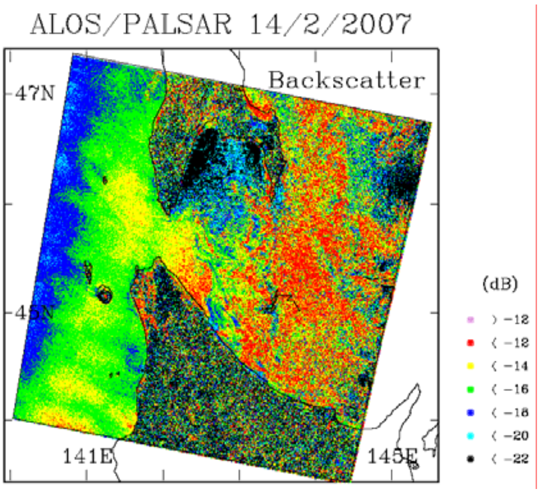

Figure 4. PALSAR BC (HH) distribution in the southern Sea of Okhotsk. The black line denotes the cruise track on February 13.

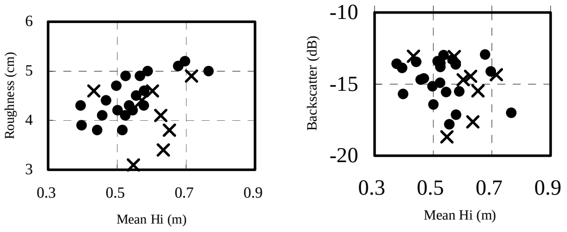

Figure 5. Correlation of ice thickness with

(a) surface roughness and (b) PLSAR BC

4. SUMMARY

In order to develop the retrieval of ice thickness distribution in SIZ from space, we examined the validity of polarimetric L-band radar backscatter data with the in situ measurements of ice thickness and surface roughness in the southern Sea of Okhotsk in 2005. The L-band BC data were obtained with airborne Pi-SAR. In situ ice thickness data were obtained with the ship-borne EM, and surface roughness was estimated by removing the ship motion from the sonic profiling data with a low-pass filter. Our analysis showed that these three kinds of data are well correlated with each other, and ice thickness, ranging from 0.44 to 1.65 m, can be estimated directly from L-band radar backscattering coefficient with the rms error of 0.19 m. This result can be interpreted as follows: In SIZ the ice thickness distribution for relatively thick ice is determined mainly by ridging activities accompanied by deformation. Thus the degree of surface roughness is well correlated with ice thickness distribution. To apply this result to PALSAR data, we planned the ship-borne measurement for validation in the Sea of Okhotsk in February 2007. However, simultaneous observation was prevented due to bad weather conditions. We are now planning the same observation in February 2008.

5. FUTURE PLAN

In addition to the observation in the Sea of Okhotsk, we are also planning to make mooring array observation off the Cape Darnley, Antarctica, as the Japanese IPY project (Fig. 6). This area is found to be an active coastal polynya area owing to the blocking effect by the ice tongue east of the area. We will deploy three sets of ice profiling sonar (IPS) and acoustic Doppler current profiler (ADCP) in the polynya area (red circles in Fig.6) from February 2008 to February 2009. By combining the IPS data and ADCP ice velocity data, thickness pseudo spatial series (topographic profile) will be also obtained. These data sets will be quite useful for the validation of satellite-derived sea ice products. Since the polynya area is considered to be thin ice area, these data sets will be used for development of thin ice thickness algorithm of ALOS/PALSAR, SSM/I, and AMSR data. Our preliminary investigation suggests that this polynya is the second highest ice production area in the Antarctic Ocean, and thus a possible area of formation of dense water and Antarctic Bottom Water. We have a plan to make a hemisphere-scale mapping of sea ice production by using the thin ice thickness algorithm which will be developed. ALOS/PALSAR data will be also used for investigation of formation and variability processes of the coastal polynya, along with the use of other satellite data and the mooring data.

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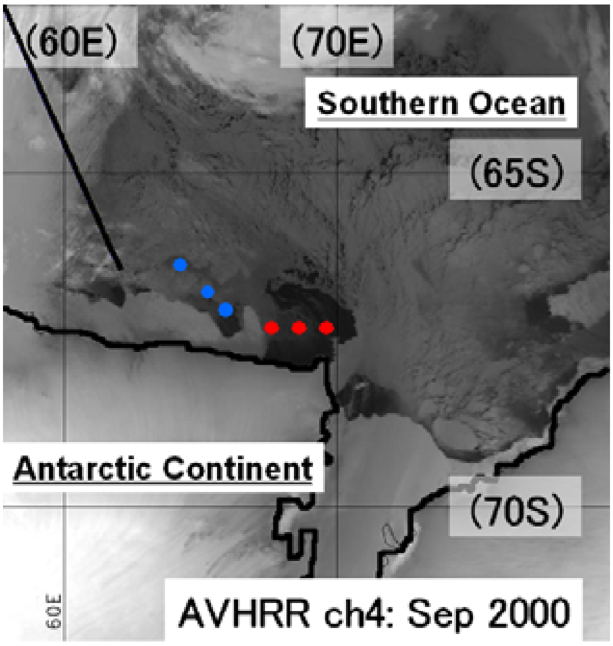

Figure 6. AVHRR image around Cape Darnley, Antarctica. Dark area indicates warmer surface temperature, implying thin ice area. Red circles denote the mooring site of IPS and ADCP. Blue circles denote the mooring site of ADCP and CT meters.

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