Investigation of Arctic Sea Ice Thickness using Space-borne Polarimetric SAR data

Jin-Woo Kim[1], Duk-Jin Kim[1], and Byong Jun Hwang[2]

1. School of Earth and Environmental Sciences, Seoul National University, Seoul 151-742, Korea
2. Scottish Association for Marine Science, Scottish Marine Institute, Argyll, PA37 1Q1, UK

1. INTRODUCTION

Space-borne synthetic aperture radar (SAR) data have been widely used to produce ice concentration (type), ice motion, ice charting (operational route planning), and iceberg detection. Recent availability of polarimetric SAR sensors (e.g., TerraSAR-X, RADARSAT-2, and ALOS PALSAR) enables us to explore the full potential of polarimetric data to derive sea ice information. Among the many sea ice parameters, sea ice thickness is the most highlighted parameters in the context of climate changes [1] and operative perspective. While large-scale ice thickness can be derived by space-borne altimetry [1, 2], the ice thickness retrieval at finer resolution for operational purpose is not reliable. It has been shown some possibility to derive the thickness of first-year ice (FYI) by using airborne L- and X-band SAR data and C-band ENVISAT ASAR data [3-5]. If successful, high-resolution ice thickness could be derived from space-borne polarimetric SAR data. It, however, still remains significant challenges to derive robust and accurate ice thickness given large variability in ice types and features in the Arctic. In this study we present results from polarimetric analysis of TerraSAR-X, RADARSAT-2 and ALOS PALSAR data, which have been acquired in conjunction of sea ice field observations. Using SAR and field data together, we explore the possibility of ice thickness retrieval over various ice types and features by using polarimetric SAR data.

2. DATA AND METHODS

We acquired fully (L-band) and dual (C- and X-band) polarimetric SAR data in the Arctic sea off the northern coast of Alaska and Greenland (Table 1). At the Greenland site, we acquired snow and sea ice thickness data along the transect line where smooth FYI, rubble multi-year ice (MYI) and ridges coexisted. For each SAR data we calculated the backscattering coefficient ratio (BCR) as described in [4]. In this study, we improved the Integral Equation Method (IEM) to be applicable to the sea ice. The dielectric constant of sea ice, the input value of the IEM [6], was estimated from Sea-Ice Thermodynamic Model (SITM) and salinity model to further examine the cause of any observed correlations between ice thickness and the BCR values. We also performed eigenvector-based decomposition to investigate different scattering mechanisms and explore the potential of ice thickness retrieval.

	TerraSAR-X	RADARSAT-2	ALOS/PALSAR
Acquisition Date/Time	2009.5.02/17:40 2009.5.13/10:09	2009.4.28/10:50 2009.4.30/10:01	2007.4.11/07:28 2007.4.11/07:28
Center frequency	9.65GHz (X-band)	5.405GHz (C-band)	1.27GHz (L-band)
Polarization	HH/VV(2009/5/02) HH/HV(2009/5/13)	HH/HV(2009/4/28) VH/VV(2009/4/30)	HH/VV/HV/VH
Spatial resolution	3m	12.5m	12.5m
Incident Angle	27.28~29.03^{o}(2009/5/02) 44.39~45.53^{o}(2009/5/13)	33.61~39.75^{o}(2009/4/28) 41.44~46.64^{o}(2009/4/30)	22.75~24.98^{o}
Location	Greenland	Greenland	Alaska

Table 1. Polarimetric SAR data acquisition in the Arctic Sea

3. NUMERICAL EXPERIMENTS

While examining the correlation between the BCR values and ice thickness, we found a good correlation for L-band SAR, but less correlation for X-band SAR. To examine the poor correlation in the X-band case, we simulated the sensibility of BCR to the surface roughness of sea-ice using the updated IEM. In this model, the backscattering coefficient is given by [6]

$$\sigma_{pp}^{o} = \tfrac{k^2}{2} \exp[-2k_y^2 \sigma^2] \sum_{n=1}^{\infty} \left| I_{pp}^{n} \right|^2 \tfrac{W^{(n)}(-2k_x,0)}{n!} \qquad (1)$$

where k_x , k_y = wave number, σ = rms height, pp = vv or hh polarization, and $W^{(n)}(-2k_x,0)$ is the Fourier transformation of the n-th power of the surface correlation function. For $W^{(n)}(-2k_x,0)$ calculation, we used generalized power law spectrum proposed by [7] to reflect the actual surface roughness of sea ice. We also applied a transition function [8] to increase the range of validity of the IEM. The L-, C- and X-band dielectric constants of sea-ice, ε_i , are necessary to simulate the backscattering coefficient using the IEM. We combined several models such as simplified two-phase mixture model, SITM, and salinity model for the calculation of the dielectric constants. The results suggested that BCR values at L-band was not sensitive to the changes of surface roughness, while the BCR values at C- and X-band varied depending on the changes of the surface roughness. This indicates that the embedded effects of surface roughness in C- and X-band SAR data prohibit the effectiveness of BCR in deriving ice thickness.

4. SCATTERING DECOMPOSITION

We further examined the potential applicability of polarimetric SAR data by using scattering decomposition methods. We applied the eigenvector-based decomposition using dual-polarimetric C- and X-band SAR data [9]. We calculate the covariance matrix, C_2, of HH and VV, and then decomposed the eigen-vectors (v) and eigen-values (λ). The results showed a good correlation between the eigen-values (λ_1 and λ_2) and the observed ice thickness. The maximum correlation of 0.7 was observed for the second eigen-value (λ_2). We also applied model-based target decomposition method [10] for L-band fully polarimetric SAR data, and calculated scattering ratios between volume and surface to examine the relation with sea ice thickness.

5. SUMMARY

We analyzed L-, C- and X-band dual or fully polarimetric SAR data in conjunction of sea ice field observation data where various ice types coexisted. The results showed a good correlation between the backscattering coefficient rations (BCR) at L-band and sea ice thickness, but not for C- and X-band SAR data. The modeling study suggested this poor correlation at C- and X-bands can be attributed to high sensitivity of the BCR values to surface roughness. We further examine the potential applicability of polarimetric SAR data by applying eigenvector decomposition. The results showed good correlation between the second eigen-value and sea ice thickness.

6. REFERENCES

[1] R. Kwok, G.F. Cunningham, M. Wensnahan, I. Rigor, H.J. Zwally, and D. Yi, “Thinning and volume loss of Arctic Ocean sea ice cover: 2003-2008,” *J. Geophys. Res.*, vol. 114(C07005), doi:10.1029/2009JC005312, 2009

[2] K.A. Giles, S.W. Laxon, and A.L. Ridout, “Circumpolar thinning of Arctic sea ice following the 2007 record ice extent minimum,” *Geophys. Res. Lett.*, vol. 35(L22502), doi:10.1029/2002008GL035710, 2008

[3] H. Wakabayashi, T. Matsuoka, and K. Nakamura, “Polarimetric Characteristics of Sea Ice in the Sea of Okhotsk Observed by Airborne L-Band SAR,” *IEEE Trans. Geosci. Remote Sens.*, vol. 42, pp. 2412-2425, 2004

[4] K. Nakamura, H. Wakabayash, K. Naoki, F. Nishio, T. Moriyama, and S. Uratsuka, Observation of Sea-Ice Thickness in the Sea of Okhotsk by Using Dual-Frequency and Fully Polarimetric Airborne SAR (Pi-SAR) Data. *IEEE Trans. Geosci. Remote Sens.*, Vol.43(11), pp. 2460-2469, 2005.

[5] K. Nakamura, H. Wakabayashi, S. UTO, K. NAOKI, F. NISHIO, and S. URATSUKA, “Sea-ice thickness retrieval in the Sea of Okhotsk using dual-polarization SAR data,” *Annals of Glaciology*, vol. 44, pp. 261-267, 2006.

[6] A.K. Fung, Z. Li, and K.S. chen, “Backscattering from a Randomly Rough Dielectric Surface,” *IEEE Trans. Geosci. Remote Sens.*, vol.30(2), pp. 356-369, 1992.

[7] Q. Li, J. shi, and K. S. chen, “A Generalized Power Law Spectrum and its Applications to the Backscattering of Soil Surfaces Based on the Integral Equation Model,” *IEEE Trans. Geosci. Remote Sens.*, vol.40(2), pp. 271-280, 2002.

[8] T.-D Wu, K. S. Chen, J. Shi, and A. K. Fung, “A Transition Model for the Reflection Coefficient in Surface Scattering,” *IEEE Trans. Geosci. Remote Sens.*, vol.39(9), pp. 2040-2050, 2001.

[9] S.R. Cloude.and E. Pottier, “A review of target decomposition theorems in radar polarimetry,” *IEEE Trans. Geosci. Remote Sens.*, vol.34(2), pp. 498-518, 1996.

[10] Y. Yamaguchi, T. Moriyama, M. Ishido, and H. Yamada, “Four-component scattering model for polarimetric SAR image decomposition,” *IEEE Trans. Geosci. Remote Sens.*, vol.43(8), pp. 1699-1706, 2005.