ENVIRONMENT MEASUREMENT FOR BOREAL REGION WITH L-BAND FULL POLARIMETRC SAR

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1. INTRODUCTION

L-band SAR is a powerful tool for forest monitoring, and ALOS/PALSAR is expected to be used for these purposes. Our research goal is to understand the radar reflection mechanism in boreal forests by using ground-based SAR and satellite SAR data, and full polarimetry data are suitable to know the scattering mechanism on the ground. There are three dominant scattering mechanisms; double-bounce scattering from tree trunk and surface, volume scattering from canopy, and surface scattering from soil surface. We report analysis result related to the surface scattering of permafrost, which commonly cover the surface in boreal forest.

Several studies have been done to detect moisture variation over permafrost area [1]-[4]. But it is essential to know the scattering mechanism to derive robust algorithm for estimating moisture level.

In this paper, we compare the results of field measurements of soil-surface parameters (soil moisture, surface roughness, and correlation length) with simultaneously acquired PALSAR full polarimetry data. Several 1- and 2-layer surface scattering models are described in section 2, and applied to our data and the results are discussed in section 5.

2. MODELS

Several models have been suggested for estimating Mv and *ks* from SAR data. Three well-known simple theoretical models have been applied to smooth, slightly smooth, and rough ground surfaces. The first of these is the small perturbation model (SPM) [5], which is valid for smooth surfaces ($ks < 0.3$). The second, the physical optics model (POM) [6], is valid for slightly rough surfaces within the parameter ranges $Mv < 0.25$, $l^2 > 2.76 \cdot s\lambda$, and $kl > 6$. The third, the geometric optics model (GOM) [6], is valid for rough surfaces and predicts that $\sigma^0_{HH} = \sigma^0_{VV}$ at all incidence angles; this model is valid within the parameter ranges $kl > 6$, $l^2 > 2.76 \cdot s\lambda$, and $ks \cdot \cos\theta > 1.5$. These 3 models can estimate only the values of σ^0_{HH} and σ^0_{VV} and not the value of σ^0_{HV} and σ^0_{VH}.

Fung [7] suggested the integral equation method (IEM) model, which describes the behavior of σ^0 for both the co-polarization and cross-polarization terms. For cases where $ks \cdot kl < 1.2 \cdot \mathrm{sqrt}(\varepsilon)$, the backscattering coefficient can be calculated using an analytical equation.

Fourier transformation of the surface correlation function is also an important parameter to describe the characteristics of the soil surface; the exponential, Gaussian, and 1.5-power forms of this function are well known. Many curves observed in fields appear to follow an exponential shape generated by the exponential correlation function [7].

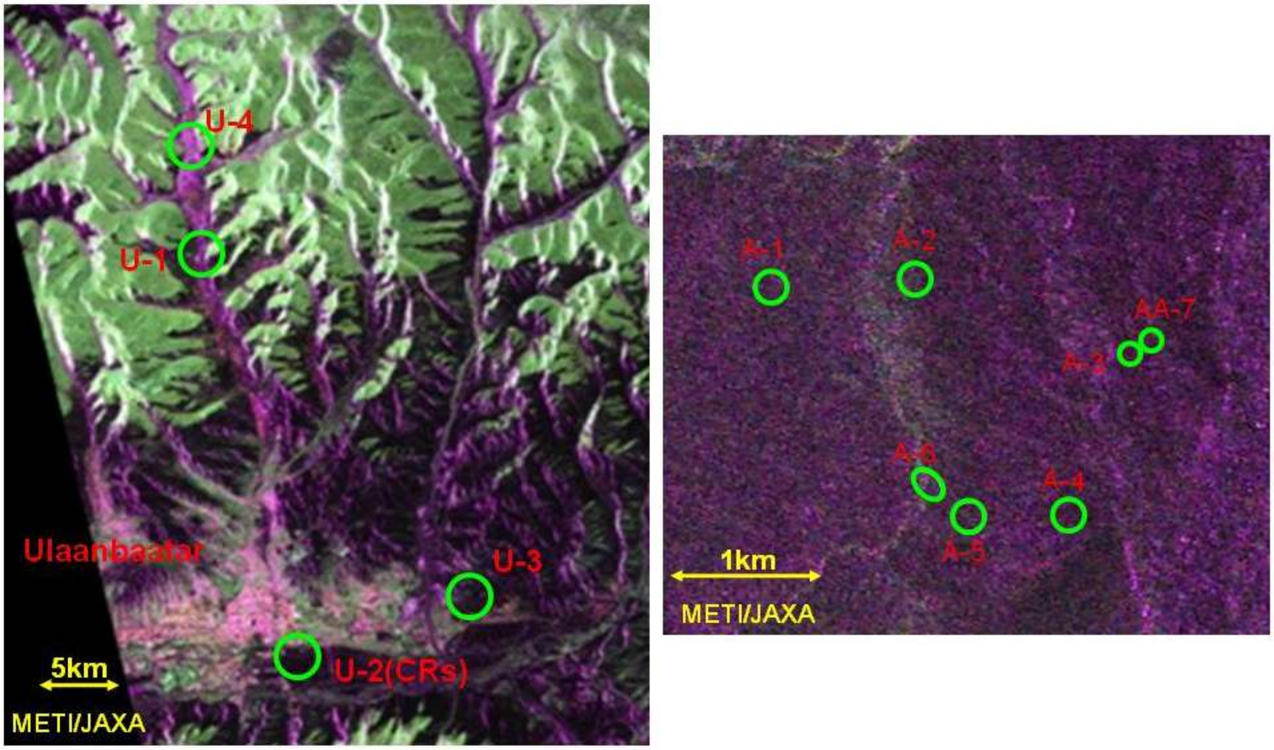
Oh [8] proposed a semi-empirical model in which some parameters were tuned using ground-based (GB) polarimetric scatterometers and AIRSAR data obtained for various soil conditions. Three parameters are defined in this model. The applicable range of the model is less than $3 \cdot ks$.

The 2-layer model is developed to describe more complex ground phenomena, such as the presence of vegetation, or snow on ice. Fung [7] used 4 terms to represent the co-polarization surface and volume backscattering of the 2 layers

A shadowing effect, caused by screening of parts of a surface by other parts, leads to large errors for large angles of incidence [9]. In this study, the local incidence angle of the PALSAR data was 24° and the calculated shadowing function was equal to unity. Thus, we were able to disregard shadowing effects when calculating σ^0 from the models.

3. TEST SITES AND PALSAR OBSERVATIONS

We performed 3 simultaneous field data collections with PALSAR full polarimetry observation in Ulaanbaatar, Mongolia (May 4, 2007), and in the Arctic National Wildlife Refuge (ANWR), Alaska, USA (July 29,



(a) Ulaanbaatar (b) ANWR

Fig. 1 Positions of test sites (green circles), displayed on the PALSAR/full polarimetry image for Ulaanbaatar (a) and Arctic National Wildlife Region (ANWR). Red: HH, Green: HV, Blue: VV. Corner reflectors (CRs) were deployed at site U-2.

Fig. 2 2.5-m trihedral corner reflectors (CRs) deployed at the U-2 site (Ulaanbaatar) during field data collections.

2007, and July 31, 2008). Other dual polarization mode (HH and HV) PALSAR data were used to check the incidence angle dependency of the backscattering coefficient, collected in ANWR, 2 weeks after the observation of full polarimetry data (August 17, 2007). The off-nadir angle was 21.5° for the full polarimetry mode and 34.3° for the dual polarization mode. The summary of PALSAR observation is presented in Table 1. PolSARPro software [10] was used to calculate entropy (H), α and anisotropy (A), which represent the radar scattering mechanisms of targets [11].

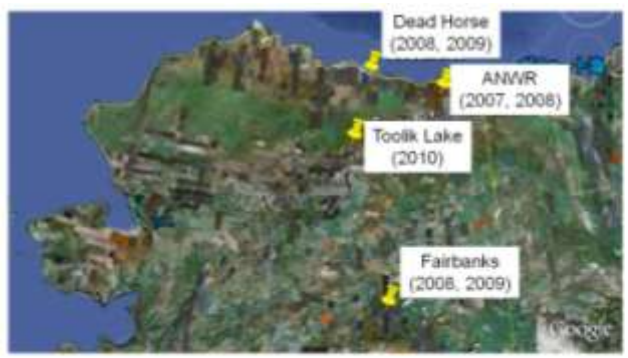


Fig. 3 Location of field experiments

PALSAR polarimetry images covering the test sites are shown in Fig. 1. The test sites are in the high-elevation steppe–tundra ecosystem of central Mongolia and the coastal tundra ecosystem of the Alaska Arctic coastal plain in the ANWR.

The active layer is a seasonally frozen-unfrozen layer that occurs above permafrost. Trees were absent in the ANWR sites because of the high latitude location

(~70°N). HH and VV polarization are dominant in the permafrost area, colored purple in Fig. 1 (b). This means the surface backscattering is dominant. Strong radar reflections are observed for very wet areas along the small stream in the middle of the image, which are colored white. High moisture values were observed in the areas (A-5 and A-6).

Full polarimetric calibration of the PALSAR data was successfully performed and reported by Shimada et al. [12]. To confirm that the channel imbalance of the PALSAR data was calibrated in our studies, we examined the scattering matrices derived from two 2.5-m trihedral corner reflectors (CRs) deployed at the U-2 site (Ulaanbaatar) during field data collections (see Fig. 2). The observed scattering matrix is:

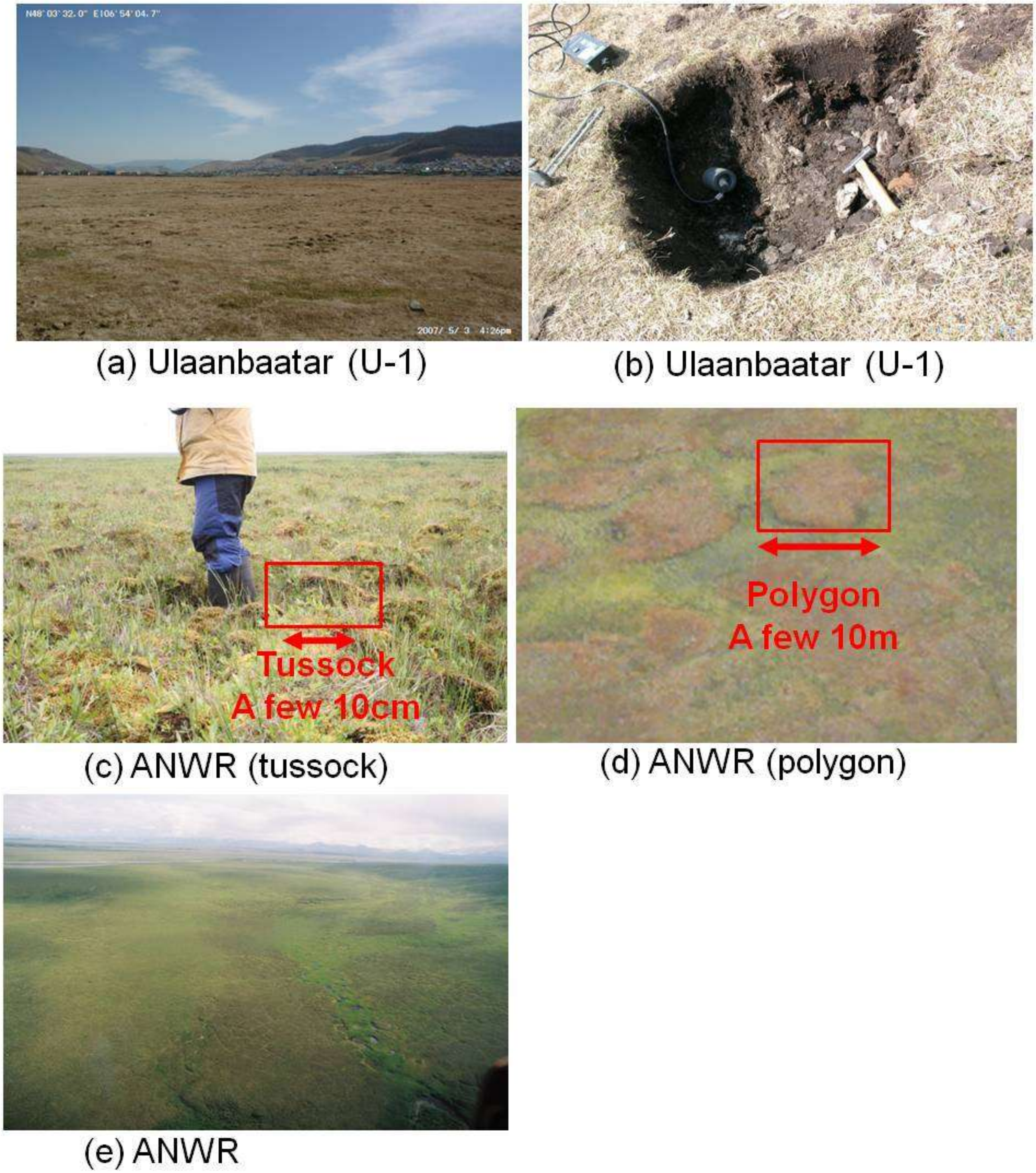


Fig. 4 Photos of some of the test sites in Ulaanbaatar, Mongolia, and the Arctic National Wildlife Refuge, Alaska, USA.

Fig. 5 Needle profilometer

Fig. 6 Data logger deployed in ANWR for a year

$$s = \begin{bmatrix} 1\angle 0^\circ & 0.07\angle 6.3^\circ \\ 0.08\angle -0.1^\circ & 0.99\angle 1.7^\circ \end{bmatrix}$$

The $\sigma^0_{HH}/\sigma^0_{VV}$ ratio is close to 1, confirming the correct full polarimetric calibration of our PALSAR data.

Additional field data collections were carried out at Deadhorse, Toolik Lake, and Fairbanks in Alaska (Fig. 3).

Field observations in Ulaanbaatar were performed at 4 test sites (U-1 to U-4). Two of the 4 sites, U-1 and U-4, were on riverbanks covered by short grasses (Fig. 4a and b); the other 2 sites were covered by dry sand. Field observations in ANWR were conducted at 6 sites in 2007 (A-1 to A-6) and 4 sites in 2008 (AA-1 to AA-3 and AA-7); note that sites A-1 to A-3 are identical to sites AA-1 to AA-3.

4. FIELD DATA COLLECTION

We measured *ks* and *kl* using a needle profilometer (Fig. 5); the profilometer was 1-m long for the measurements.

Fig. 7 Portable full polarimetric ground-based scatterometor.

Soil moisture was measured using time-domain reflectometry (TDR-type sensor; TRIME-FM2) in Ulaanbaatar and ANWR in 2007 and frequency-domain reflectometry (FDR-type sensor; Decagon) in ANWR in 2008. These systems directly measure the ε value, and ε is converted to soil moisture using the Topp equation [13]. The frequency used for the measurements is influenced by salinity and the imaginary part of the dielectric constant [14]. The TDR system uses the frequency range of 0.1–5 GHz, while the FDR system can achieve a signal frequency with a maximum oscillation of about 100 MHz. It is, therefore, preferable to compare PALSAR data, whose frequency is 1.27 GHz, with TDR values.

Other data collections had been carried out with data logger (Fig. 6) to measure soil moisture for a year, and portable full polarimetric ground based scatterometor (Fig. 7) to detect radar reflection from permafrost. These data are now under investigating.

Measured field parameters range from 4.2 to 78.9 Mv, 0.28 to 1.13 *ks*, and 2.0 to 5.6 *kl*. There was insufficient time to measure the surface roughness at the U-4 site in Ulaanbaatar; we therefore substituted the value of the surface roughness determined at U-1, where similar roughness was observed. Roughness values measured at sites A-1, A-2, and A-3 in 2007 were also used for sites AA-1, AA-2, and AA-3, respectively, in 2008, because roughness does not significantly change in 1 year.

The averaged surface correlation function derived for the U-1 and A-3 sites are compared with Exponential, Gaussian, and 1.5-power forms of the correlation function. The exponential form shows a good fit with our data, particularly near the peak, consistent with previous reports [7], and was therefore used in the theoretical model.

5. RESULTS AND DISCUSSION

We used PALSAR data processed by the Earth Observation Center of the Japan Aerospace Exploration Agency (JAXA) and calculated the backscattering coefficient (σ^0) for each polarization and value of H, α, and A. The α angle ranges from 5° to 25°, and H is less than 0.5. These values are categorized as Zone 9 in the H/α classification scheme [11], which represents low entropy scattering processes such as surface scattering. We confirmed that our test sites are correctly categorized by using PALSAR full polarimetric data.

Three models; IEM model, Oh model, and 2-layer model, were applied to the PALSAR data.

5.1. Integrated equation method model

Observed σ^0_{HH} and σ^0_{VV} values are compared with the IEM model, which included the Mv and surface parameter values measured in the field. The $\sigma^0_{co\text{-}pol}$ values in the Ulaanbaatar data are moderately matched with those calculated by the IEM. On the other hand, the $\sigma^0_{co\text{-}pol}$ values in the ANWR data were 5 to 7 dB lower than those calculated by the IEM model.

As noted by Yoshikawa et al. [15], sphagnum moss has a remarkable capacity to absorb and retain moisture, and it can hold 20–30 times its weight in water. This fact suggests that the variation of Mv with depth, due to effects of the sphagnum moss layer, may contribute to variations in the $\sigma^0_{co\text{-}pol}$ values. Using the IEM model, we calculated the $\sigma^0_{co\text{-}pol}$ value assuming a 10% soil moisture value for the ANWR site, and obtained a good fit between model results and observed data.

5.2. Oh model

The Oh model was also applied to compare field observations with PALSAR data. Except for the U-2 and U-3 sites, the σ^0_{VH} values derived from PALSAR data are well matched to values calculated using the Oh model, which incorporates soil moisture and surface parameter values measured in the field.

5.3. 2-layer model

A new 2-layer model, combined IEM model with Oh modek, is suggested based on the 2-layer model described in section 2, and is used to calculate backscattering of polarization data. The new 2-layer model was applied to the A-1 site, where a data logger had been deployed to monitor moisture levels. Dual polarization-mode PALSAR data collected 2 wks after the field data collection were used in this analysis. Albedo and optical depth values were changed from 0.1 to 1, and σ^0 in co- and cross- polarizations were calculated from the 2-layer model.

Several combinations of albedo and optical depth values yielded σ^0 discrepancies of <2 dB between PALSAR data and results of the 2-layer model, and the model describe the PALSAR data well Detailed discussion is summarized in [16].

6. SUMMARY

Three simultaneous collections of field data and ALOS/PALSAR full polarimetry observations were performed in Ulaanbaatar, Mongolia (2007), and Alaska, USA (2007 and 2008). Mineral soils or small amounts of grasses covered the ground surface in Ulaanbaatar. The ground surface in Alaska, on the other hand, is covered by an active layer of permafrost consisting of a few to 10 cm of sphagnum moss and organic and mineral layers.

From the analysis of field and PALSAR data, we compiled the following results:

1. The $\sigma^0_{co\text{-}pol}$ values obtained in Ulaanbaatar using PALSAR data are well matched to results of the IEM model (within a few dB), while the $\sigma^0_{co\text{-}pol}$ values obtained in Alaska were 5 to 7 dB lower than predicted by the IEM model.
2. Unlike $\sigma^0_{co\text{-}pol}$ values, σ^0_{VH} values estimated from the Oh model are well matched to those derived from PALSAR data, in both Ulaanbaatar and Alaska.

From these observations and other facts collected in the field, we conclude that the sphagnum moss layer plays an important role in radar backscattering processes in permafrost regions, and is a main contributor to the $\sigma^0_{co\text{-}pol}$ backscattering component; the underlying organic and mineral layers, on the other hand, contribute to the $\sigma^0_{cross\text{-}pol}$ component. A 2-layer model, applied to one of the test sites in Alaska, provided a good prediction of σ^0 values derived from PALSAR data obtained with off-nadir angles of 21.5° and 34.3°, for both co-polarization and cross polarization results.

6. ACKNOWLEDGMENTS

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6. REFERENCES

[1] L. L. Bourgeau-Chavez, E. S. Kasischke, K. Riordan, S. M. Brunzell, M. Nolan, E. J. Hyer, J. J. Slawski, M. Medvecz, T. Walters, and S. Ames, “Remote monitoring of spatial and temporal surface soil moisture in fire disturbed boreal forest ecosystems with ERS SAR imagery,” Int. J. Remote Sens., vol. 28, pp. 2133-2162, 2007

[2] E. S. Kasischke, L. Morrissey, J. B. Way, N. H. F. French, L. L. Bourgeau-Chavez, E. Rignot, “Monitoring seasonal variations in boreal ecosystems using multi-temporal spaceborne SAR data,” Canadian Journal of Remote Sensing,, vol. 21, no. 2, pp. 96-109, 1995

[3] N. H. F. French, E. S. Kasischke, L. L. Bourgeau-Chavez, and P. A. Harrell, “Sensitivity of ERS-1 SAR to variations in soil water in fire-disturbed boreal forest

ecosystems," International Journal of Remote Sensing, vol. 17, no. 15, pp. 3037-3053, 1996
[4] E. S. Kasischke, L. L. Bourgeau-Chavez, and J. F. Johnstone, "Assessing spatial and temporal variations in surface soil moisture in fire-disturbed black spruce forests in Interior Alaska using spaceborne synthetic aperture radar imagery—Implications for post-fire tree recruitment," Remote Sensing of environment, vol. 108, pp. 42-58, 2007
[5] M. F. Chen and A. K. Fung, "A numerical study of the regions of validity of the Kirchhoff and small-perturbation rough surface scattering model," Radio Science, vol. 23, no. 2, pp. 163-170, 1988
[6] F. T. Ulaby, F. Kouyate, A. K. Fung, and A. J. Sieber, "A backscatter model for a randomly perturbed periodic surface," IEEE Trans. Geosci. Remote Sensing, GE-20, no. 4, pp. 518-527, 1982
[7] A. K. Fung, "Microwave scattering and emission models and their applications," Artech House, Norwood, MA, 572 p., 1994
[8] Y. Oh, "Quantitative retrieval of soil moisture content and surface roughness from multipolarized radar observations of bare soil surfaces," IEEE Trans. Geosci. Remote Sens., vol. 42, no. 3, pp. 596-601, 2004
[9] P. Beckman, "Shadowing of random rough surface," IEEE Trans. Antennas Propagat., AP-13, pp. 384-388, 1965
[10] E. Pottier, L. Ferro-Famil, S. Allain, S. Cloude, I. Hajnsek, K. Papathanassiou, A. Moreira, M. Williams, A. Minchella, M. Lavalle, and Y. Desnos, "Overview of the PolSARpro V4.0 software. The open source toolbox for polarimetric and interferometric polarimetric SAR data processing," Proc.of IEEE International Geoscience and Remote Sensing Symposium,, vol. 4, pp. 936-939, 2009
[11] S. R. Cloude and E. Pottier, "An entropy based classification scheme for land applications of polarimetric SAR," IEEE Transactions on Geoscience and Remote Sensing, vol. 35, no. 1, pp. 68-78, 1997
[12] M. Shimada, O. Isoguchi, T. Tadono, and K. Isono, "PALSAR radiometric and geometric calibration," IEEE Trans. Geosci. Remote Sens., vol. 47, no. 12, pp. 3915-3932, 2009
[13] G. C. Topp, J. L. Davis, and A. P. Annan, "Electromagnetic determination of soil water content," Water resource Res., vol. 16, pp. 574-582, 1980
[14] T. J. Dean, J. P. Bell, and A. J. B. Baty, "Soil moisture measurement by an improved capacitance technique, Part 1. Sensor design and performance," Journal of Hydrology, vol. 93, pp. 67-78, 1987
[15] K. Yoshikawa, P. P. Overduin, and J. W. Harden, "Moisture content measurements of moss (*Sphagnum* spp.) using commercial sensors," Permafrost and Periglacial Processes, vol. 15, pp. 309-318, 2004
[16] Manabu Watanabe, Gaku Kadosaki, Yongwon Kim, Mamoru Ishikawa, Keiji Kushida, Yuki Sawada, Takeo Tadono, Masami Fukuda, and Motoyuki Sato, "Analysis of the sources of variation in L-band backscatter from terrains with permafrost", IEEE Trans. Geosci. Remote Sens., Submitted.

Table 1. Summary of PALSAR observations and field data collections.

Place		Ulaanbaatar	ANWR		
PALSAR	Observation date	May 4, 2007	July 29, 2007	August 17, 2007	July 31, 2008
	Mode	Polarimetry, 21.5°		HH+HV, 34.3°	Polarimetry,
	Direction	Ascending	Descending	Ascending	Descending
Field data collection site	Term	May 2–7, 2007	July 28–Aug. 4,		July 28–Aug. 3,
	No. of test sites	4	6		4
	Parameters measured	Soil moisture and surface roughness	Soil moisture (TDR*), surface roughness, biomass, and conductivity		Soil moisture (FDR) and surface roughness

* Time-domain reflectometry, ** Frequency-domain reflectometry