Study on the Forest Observation in Kushiro Wetland by using Dual-Frequency and Fully Polarimetric Airborne SAR (Pi-SAR) Data

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Abstract: We chose the Kushiro wetland in Hokkaido, Japan, as a test site to monitor wetland areas. Synthetic aperture radar (SAR) can carry out continuous observation in any weather conditions, and can therefore be used to observe high humidity areas such as wetlands. We applied multi-parameter SAR data (dual-frequency, multi-polarization, and multi-incidence angle) to monitoring the wetland forest. To find the optimum incidence angle and polarization for monitoring the wetland biomass, a simple backscattering model of wetland vegetation was developed and applied to estimate backscattering coefficients for different biomass and surface conditions.

Keywords: Wetland, Forest, Polarization, SAR.

1. Introduction

The Kushiro wetland in Hokkaido, Japan, is mostly distributed in a moist, low-temperature area at high latitudes. The wetland contains a peat bog formed from an accumulation of undecomposed plant matter. Peat bogs are similar to aerial parts of the biomass in accumulating carbon. Since the amount of carbon in wetlands cannot be ignored, the wetland ecosystem must be monitored. Observing changes in wetland forests will improve our understanding of the process of wetland metamorphosis.

We chose the Kushiro wetland in northeastern Hokkaido as a test to monitor wetland areas. Since SAR can carry out observations continuously in any weather conditions, it is useful for observing high humidity areas such as wetlands. This paper describes some of the results of applying multi-parameter SAR data (dual-frequency, multi-polarization, and multi-incidence angle) to monitor the wetland forest. To find the optimum incidence angle and polarization for monitoring the wetland biomass, a simple backscattering model of wetland vegetation was developed and applied to estimate backscattering coefficients for different biomass and surface conditions.

2. Test Site

We chose the Kushiro wetland as the test site for monitoring a wetland area using SAR because the vegetation of the Kushiro wetland resembles that of other high-latitude wetland areas [1]. The ground truth acquisition sites were placed on the right side of the Kushiro River. There was a total of seven points; the northern sites were N1 to N3, and the southern sites were S1 to S4. The purpose of establishing both northern and southern sites was to assess backscatter from the wetland forest areas with different ground-surface conditions. The ground surface under the forest was as follows: the northern sites were flooded and the southern sites were covered with peat bog.

3. Data Acquisition

1) SAR Data

The National Institute of Information and Communications Technology (NICT) and the Japan Aerospace Exploration Agency (JAXA) have jointly developed an X- and L-band SAR system called Pi-SAR (polarimetric and interferometric-SAR) which is installed on board a Gulfstream II aircraft. The resolution in both the azimuth and range directions is 1.5 m for the X-band and 3.0 m for the L-band. Both SARs can make fully polarimetric observations.

On 9 May 2003, X-band and L-band data were acquired by the Pi-SAR along three flight paths in an east to west direction, with the incidence angle changing to 23°, 36°, and 47° at the scene center. Each of the scenes analyzed had a 5 km^2 footprint. To compare the SAR data with the ground-truth data, the Pi-SAR data were smoothed using a moving average filter with a window size of 5 by 5, collection for backscattering coefficients, and map projection.

2) Ground Truth Data

The ground truth was acquired in synchrony with the Pi-SAR observations. It was assumed that backscatter depended only on the wetland forest, and was not affected by grass because there is no grass in May. The basic structural parameters of the biomass were considered to be the height and diameter at breast height (DBH) of the trees.

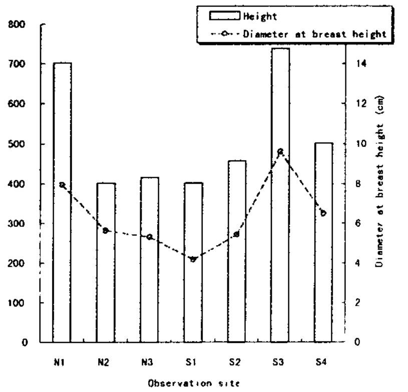

Fig. 1. Results of ground truth data acquisition of the tree height and diameter of breast height of alder.

Alder is the dominant species of the wetland forest. Therefore, the ground-truth data was acquired with a focus on these parameters. To measure the parameters, an observation area of 5 m by 5 m was established at each site. The measurement results of the height and the DBH at each site are shown in Fig. 1.The height and DBH were derived from at all sites. The measurements ranged from 4.0 to 7.3 m, and 4.2 to 9.6 cm, respectively.

4. Data Analysis

We investigated the relationship between the ground-truth data and the backscattering coefficients. The backscattering coefficients increased as the height or DBH increased for all frequencies and incidence angles.

Characteristics of the incidence angle and polarization can be seen in these relationships. Moreover, we found that the backscattering coefficient for HH polarization was stronger than that for VV polarization in the northern sites (flooded surface). Conversely, the backscattering coefficient for VV polarization was stronger than that for HH polarization in the southern sites (peat bog surface).

This suggests that it may be possible to classify the ground-surface conditions under wetland forests by using the backscattering coefficients for both HH and VV polarization. Because of the L-band's high transmissivity of the forest canopy, the discussion in this paper is based on the L-band data.

5. Backscattering Model of Wetland Forest

1) Characteristics of Model

The backscattering model of the wetland forest was based on the following considerations:

(1) The interaction of three layers, air/alder/ground surface, is assumed.
(2) The alder canopy layer determines the dielectric constant in changes in volume density.
(3) First-order scattering is considered in the microwave propagations.
(4) For a flooded ground surface, the backscatter deals with specular reflections without considering the contribution to roughness.
(5) For a peat bog ground surface, backscatter from the peat bog is considered, which means that surface scattering is caused by surface roughness.

2) Backscattering Model

In unforested areas, an incident microwaves reach the ground surface. In forested areas, however, backscatter is generated by scattering from the forest canopy. Both the flooded surface and the peat bog surface produced upward scattering dominated by surface scattering. Therefore, a backscattering mechanism was considered in relation to microwave propagation and attention was focused on the interaction between the canopy of the wetland forest and its boundary. Scattering paths in the developed model is illustrated in Fig. 2.

Here, the backscattering coefficient σ^0 from the wetland forest can be written as [2]

$$\sigma^0 = 4\pi\cos\theta(1-\Gamma_0)\cdot \left\{\left(\frac{2\Gamma_{sb}\Gamma_{bb}}{L_b^2}+\Gamma_{db}\right)+\left(\frac{2\Gamma_{st}\Gamma_{bt}}{L_t^2}+\Gamma_{dt}+\Gamma_g\right)\right\} \quad (1)$$

where θ is the incidence and scattering angle, and Γ_0, Γ_{db}, Γ_{dt}, Γ_g, $\Gamma_{sb}\Gamma_{bb}$, $\Gamma_{st}\Gamma_{bt}$ are power reflectivity coefficients of scattering from the boundary of the air/canopy, direct scattering from alder trunks and branches, direct ground surface scattering from the peat bog, and double bounce scattering caused by interaction between branch/ground surfaces and trunk/ground surfaces, respectively. L_b and L_t are one-way power loss factors for the canopy of branches and trunks.

3) Calculation Procedure

Scattering from the wetland forest was calculated by the sum of the first-order incoherent scattering of the reflectivity coefficient of the air/canopy boundary, the volume extinction coefficient of the canopy, and a scattering cross-section of the alder. The average dielectric constant of the canopy was calculated using a Two-Phase Mixture Model [3], where the canopy was assumed to be composed of air and alders. The volume extinction coefficient is the sum of the volume absorption coefficient and the volume scattering coefficient, which were calculated using the average dielectric constant of the canopy and the scattering cross-section of the alder, respectively. The scattering cross-section of the alder was modeled with a finite length dielectric cylinder [4].

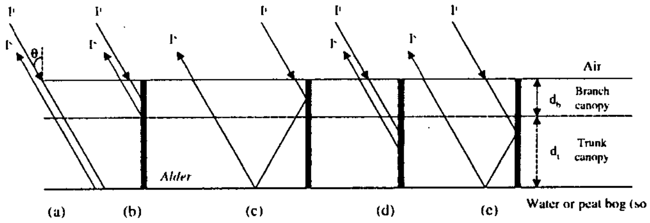

Fig. 2. Schematic diagram of scattering paths considered in the developed model. In this figure, θ is incidence and scattering angle, d_b and d_t are the height of branch and trunk, respectively, and Γ^i and Γ are the intensity of incidence and scattering, respectively. (a) Direct scattering from ground surface. (b) Direct scattering from branch. (c) Double bounce scattering caused by interaction of branch and ground surface. (d) Direct scattering from trunk. (e) Double bounce scattering caused by interaction of trunk and ground surface.

In the case of the peat bog surface, the backscattering component was calculated using an Integral Equation Method Model (IEM) [5]. The double-bounce scattering caused by the alder/ground surface interaction was also calculated by multiplying the bistatic scattering components of the alder trees and the ground surface.

4) Calculation Results

We considered that backscatter from alder with a difference in the ground surface conditions was dominated by scattering paths from the air/alder/ground surface. We investigated the dominant scattering paths from the difference in ground surface conditions by calculating the power reflectivity coefficient of each path (see Fig. 2) and the power reflectivity coefficient was calculated for different scattering paths and its result is shown in Fig. 3. As an example, the calculation result by assuming the maximum biomass of the alder in test site is shown in this figure.

Here, Fig. 3 (a) shows the case of a flooded surface, and confirms that the scattering path is significantly dominated by double-bounce scattering from alder/water. Fig. 3 (b), on the other hand, shows the case of a peat bog surface, and confirms that the scattering path is dominated the direct scattering from peat bog more than double-bounce scattering from alder/peat bog.

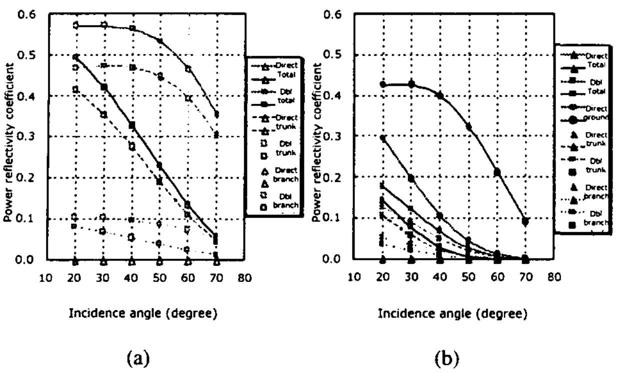

Fig. 3. Calculation results of the power reflectivity coefficient each scattering path by assuming the maximum biomass of the alder. (a) Flooded surface. (b) Peat bog surface.

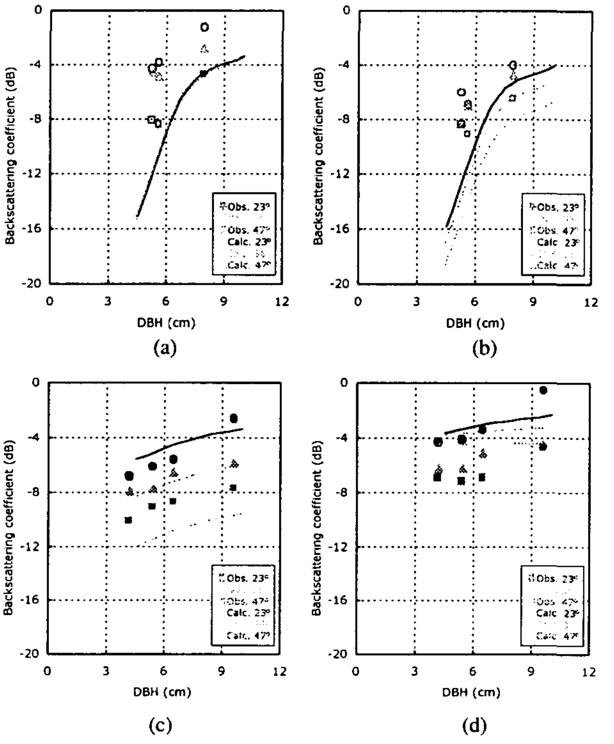

Fig. 4. Calculation results using the developed scattering model for wetland forest, which was compared to observation results. This figure is relationship between in tree height of alder as biomass change and backscattering coefficient with changing incidence angle. (a) HH polarization at flooded surface. (b) VV polarization at flooded surface. (c) HH polarization at peat bog surface. (d) VV polarization at peat bog surface.

We could find the dominant scattering path, which was double-bounce scattering from alder/water at flooded surface and direct scattering from the peat bog at the peat bog surface by calculating the power reflectivity coefficient from different paths. And we found that the backscattering coefficient for HH polarization was stronger than the backscattering coefficient for VV polarization for the flooded surface, and the scattering path was dominated by the double-bounce scattering of the alder/ground surface. However, the backscattering coefficient for VV polarization was stronger than that for HH polarization for the peat bog surface, and the scattering path was dominated by direct scattering from the ground surface. The calculated results agreed well with the observation results is shown Fig. 4.

5. Conclusions

The Kushiro wetland in Hokkaido was chosen as the test site for using Pi-SAR to observe a wetland forest. We carried out ground truth observations and experiments in synchrous with Pi-SAR data acquisition in May 2003 when there was no grass growing. The relationship between tree height or DBH and the backscattering coefficient at the test sites indicated that the backscattering coefficient increased as the height and DBH increased for all frequencies and incidence angles.

We also found that the backscattering coefficient of an excess polarization was different with different surface conditions. Then, a simple backscattering model for wetland forest was developed and applied to derive the backscattering coefficient in different biomass and ground surface conditions. This model could explain the scattering mechanism of the wetland forest biomass and the underlying ground surface conditions.

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