ESTIMATED SOIL MOISTURE IN VEGETATED AREA USING MULTITEMPORAL MULTIPOLARIZATION DATA

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Abstract — Alpine ecosystem is the most sensitive terrestrial ecosystem to global climate change. Recently, a dwarf bamboo species, *Sasa kurilensis*, (Poaceae), has invaded into alpine snow-meadows in the wilderness area of the Taisetsu Mountains, northern Japan. The spatial distribution and seasonal changes in soil moistures are key parameter in numerous environmental studies at both regional and global scales including hydrological, ecological, climatic and agricultural fields. However, the natural variability and complexity of vegetation canopy and surface roughness significantly affect the sensitivity of backscatter from soil. This study indicates a new method to estimate surface soil moisture in high density vegetated area in the Taisetsu Mountains with an L-band dual-polarization (HH and HV) radiometer measurements. For dense vegetated surfaces, we used the multitemporal and multipolarization backscatter coefficient data and the subtraction methods to provide the estimation of vegetation effects. After the soil moisture corrected based on vegetation phenology, the surface soil moisture can be inferred by the estimated surface backscatter signals.

Keywords —alpine environment, a new method of soil-moisture estimation, high mountain ecosystems, multipolarization data

I. INTRODUCTION

The impact of global warming caused by climate change on terrestrial ecosystems will be particularly prominent in arctic regions and alpine belts [1]. It is predicted that the biodiversity of alpine and subalpine ecosystems will be more seriously affected by climate change than that of other ecosystems [1]. Recently, a dwarf bamboo species, *Sasa kurilensis* (Poaceae), has invaded into alpine snow-meadows in the wilderness area of the Taisetsu Mountains, northern Japan [2] [3]. Acceleration of snowmelt time in addition to the increase in temperature may cause soil desiccation during summer in alpine regions, which should promote rapid vegetation change. During the period of last 30 years, several herbaceous species in alpine meadow have been replaced by dwarf bamboo (*Sasa kuriliensis*) in the central part of the Taisetsu Mountains [G. Kudo, unpublished data]. Because human impact is negligible in this region, this vegetation change may reflect the indirect effects of global climate change on alpine ecosystem. Therefore, the quantification of vegetation dynamics at regional scale is very important to access the global change impact on alpine ecosystems.

In recent years, the snowmelt period has been starting earlier from year to year in the Taisetsu Mountains [4]. This has led to concerns that the early snowmelt is leading to progressive soil dehydration, which creates an environment suitable for dwarf bamboo growth, and the alpine vegetation will rapidly decline due to the invasion of dwarf bamboo and dehydration. *Pinus pumila* (Japanese stone pine) has a huge biomass in the alpine zone and its growth trend may also have a great impact on other alpine vegetation. However, there is little information about factors causing the expansion of dwarf bamboo and stone pine. In order to identify the environmental factors causing rapid vegetation changes, it is important to analyze seasonal fluctuations in soil moisture in changing vegetation areas. In particular, it is essential to estimate the soil moisture content situation and analyze seasonal changes over a wide area. However, since mountain areas do not have many days of good weather, it is difficult to monitor vegetation and surface properties using conventional optical satellite sensors [5] [6]. In addition, the roughness height of stone pine and dwarf bamboo greatly affects the algorithm for the estimation of the soil moisture content when using microwave backscattering data. Therefore, in this study, aerial photographs were analyzed in order to detection of changing vegetation area and determine the expansion area of dwarf bamboo and stone pine. Then, a model of estimation of soil moisture in vegetated area was based on the vegetation phenology differences and using the multitemporal and multipolarization backscattering coefficients was developed by utilizing the characteristics that the seasonal changes of dwarf bamboo and stone pine are much smaller than the seasonal changes of soil moisture content. Based on the model, the seasonal changes in soil moisture content in the changing vegetation area were studied

II. THE STUDY OBJECTIVES

About 98 *ha* of land in the central part of the Goshikigahara area (Fig. 1: altitude: 1,700 - 1,800 meters, $43^0$33'N, $142^0$54'E) on the Taisetsu Mountains, in Hokkaido Japan was selected as the multitemporal ALOS PALSAR HH/HV polarization data in June 19, Jull 7, August 4, August 21, September 19 and October 6, 2010. The field measurement of plants species and soil moisture (using ©Hydrosense, Campbell Scientific Inc. with a 12 cm probe) of study area was taken in July, August and September four years of 2008, 2009, 2010 and 2011.

The objective of the study is to establish the remote sensing method for the estimation of soil moisture in a large scale, which is covered with dense vegetation. It is necessary to take into account the impact of the vegetation (roughness height). Therefore, the method for identifying seasonal fluctuations of soil moisture content over large areas was developed using the multitemporal and the multipolarization microwave backscattering coefficients (σ^0) for densely vegetated areas.

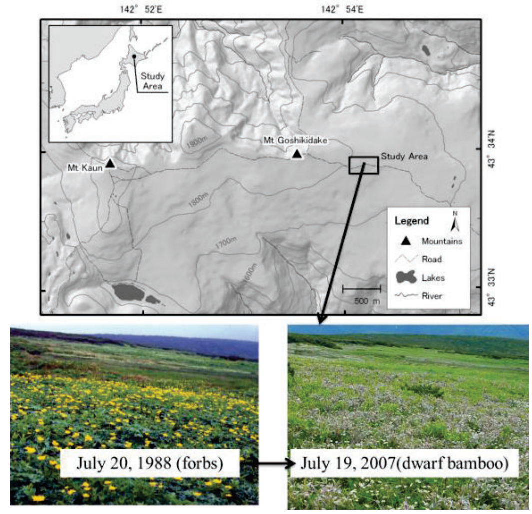

Fig. 1. The study area (Where, the picture shows the alpine vegetation change to dwarf bamboo)

III. METHODOLOGY AND RESULT

For modeling backscatter from vegetation canopies using radar data, a common approach is to first develop direct models simulating the backscattering coefficient of a canopy with known characteristics. These models include the following types: empirical model, theoretical model, and semiempirical model [7]. In semiempirical water-cloud models, the canopy is represented by ``bulk" variables such as leaf area index (LAI) or total water content, and because of the parsimonious use of parameters, these models can be easily inverted; they are, therefore, good candidates for use in retrieval algorithms [7] [8]. In this context, radar backscattering from a canopy can be expressed as the sum of contributions due to (i) volume scattering in the canopy itself, (ii) surface scattering by the underlying ground surface, and (iii) multiple interactions involving both the canopy and the ground surface. The water-cloud models represent the power backscattered by the whole canopy (σ^0) as the incoherent sum of the contribution of the vegetation (σ^0_{veg}) and the contribution of the underlying soil (σ^0_{soil}), which is attenuated by the vegetation layer. For a given incidence angle q, the backscatter coefficient is represented in water-cloud models by the general form

[6] [9]:

$$\sigma^0 = \sigma^0_{canopy} + \sigma^0_{canopy+soil} + \tau^2 \sigma^0_{soil} \quad (1)$$

Where, τ^2 are the two-way vegetation transmissivity. The first term represents the scattering due to the vegetation canopy, the second term represents the interaction between the vegetation canopy and the soil underneath and accounts for multiple scattering effects, and the third term represents the scattering from the soil layer. With the canopy (roughness) effect, the study assumed that the seasonal changes (growth) of the roughness height of dwarf bamboo and stone pine over one month does not affect the backscattering signal, based on the penetration properties of the L-band microwave through the plant layer and the phenological characteristics of dwarf bamboo and stone pineBased on this assumption, the following equation was created:

$$\Delta VSM = \Delta f(R, m_s) \approx \Delta\sigma^0_t = (\sigma^0_{t2} - \sigma^0_{t1}) \quad (2)$$

Where, R is roughness; m_s is the volumetric soil moisture (VSM) surveyed; ΔVSM is seasonal changes in the soil moisture; $\Delta\sigma^0_t$ is the difference between backscattering coefficients; σ^0_{t1} and σ^0_{t2} are backscattering coefficients from soil in season t2 and season t1, respectively.

In the development of the algorithm, the fact that the seasonal changes in dwarf bamboo and stone pine were much smaller than the seasonal changes in other alpine plants and soil moisture content was used to develop a model which used differences in microwave backscattering coefficients while taking into consideration the phenology. The moisture contents in the soil under specific vegetation in the Goshikigahara area were then identified. When looking at the seasonal fluctuations of soil moisture in 2010 in areas under stone pine, dwarf bamboo and alpine plants, the soil moisture content in the Goshikigahara increased in general from mid-June to early July, except for a decrease in some areas covered by dense dwarf bamboo. In August, September and October, there was a clear soil moisture content decrease (dehydration) in most areas under dense dwarf bamboo. At the edges of some expanding area of dwarf bamboo (where dwarf bamboo was invading alpine vegetation areas), the increases in soil moisture content were observed. There were no major fluctuations in areas where alpine plants occupied a wide area from August to October, but the areas showed slight dehydration.

The field measurements revealed that soil moisture contents in the Goshikigahara ranged between 65% and 80%. The moisture contents on steep slopes of the southeast side were relatively low. Dwarf bamboo has expanded into this area.

The subtraction results of multitemporal and multipolarization backscattering coefficients data to estimate soil moisture conditions in the Goshikigahara area calculated from equation 2 show in Fig. 2.

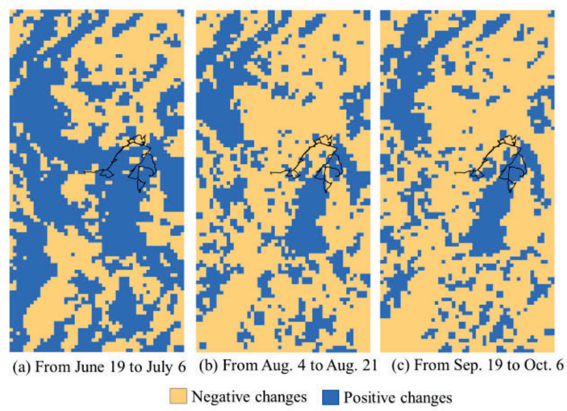

Fig. 2 (a, b, c). Seasonal change in soil moisture condition extracted from L-band PALSAR multitemporal and multipolarization backscattering coefficients. The light color shows soil moisture negative changes and the blue color shows the soil moisture positive changes (where, the black lines show the route and location of the field survey).

The Fig. 2 (a, b, c) shows the subtraction results of backscattering coefficients difference between (a) July 6 and June 19, 2010 (the positive change area is 64%); August 21 and August 4, 2010 (the positive change area is 47%); and October 6 and September 19, 2010 (the positive change area is 44%) in the test site. The positive values a (blue color) indicate an increase in soil moisture, the negative values (light color) indicate a decrease in soil moisture, and the values close to zero indicate that the changes were small. It was confirmed that soil moistures decreased in areas where dwarf bamboo grew densely in mid-June to early July and that soil moistures increased in many areas as the snow melted. However, from early to late August and from September to October, soil moistures clearly decreased (dehydration) in areas under dense dwarf bamboo over wide area. There was an exception: soil moistures increased at the edges of dwarf bamboo expanding areas. It was confirmed that soil moistures were relatively constant from August to October in areas where alpine plants covered a wide area, but the areas showed slight dehydration.

IV. DISCUSSION

Estimation of soil moisture in densely vegetated area is very difficult, because the microwave backscatter is influenced by the roughness surface height. Based on the accurate scattering model, both the soil moisture and surface roughness can be retrieved from the polarimetric backscatter measurements with a good accuracy for bare-soil surfaces. In the present study, we provide a new method to estimate the surface soil moisture in dense vegetation area in the Taisetsu Mountains with an L-band dual-polarization (HH and HV) radiometer measurement considering vegetation phenology. For high dense vegetated surfaces, we used the multitemporal and multipolarization backscatter coefficient data and the subtraction methods to provide the estimation of the vegetation effects. After the soil moistures corrected based on vegetation phenology, the surface soil moistures can be inferred by the estimated surface backscatter signals.

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