Process Study for Developing Algorithms to Quantitatively Estimate Hydrological Parameters Based on ALOS Data
-A Case Study of Soil Moisture Estimation with Existing Algorithm-

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Abstract
Soil moisture is important for fields not only hydrology but also meteorology. It plays important roles in the interactions between the land surface and the atmosphere, as well as in the partitioning of precipitation into runoff and ground water storage. In spite of its importance, soil moisture is not generally used for weather forecasting and water resources management because it is difficult to measure on a routine basis over large areas. The objective of this study is to develop algorithms to estimate land hydrological parameters *i.e.* soil moisture and snow parameters using ALOS data.
As first step of this study, we applied existing algorithm to PALSAR data to estimate surface soil moisture. The test sites are located in the Mongolian Plateau, where is spatially homogeneous with basically flat terrain features, and three Automatic Weather Stations (AWSs) and twelve Automatic Stations for Soil Hydrology (ASSH) are installed and continuously maintaining. We derived surface soil moisture maps with 100m spatial resolutions and validated seasonal variation using ground truth data.

Keywords: ALOS, Daichi, PALSAR, Soil moisture

1. INTRODUCTION

The objective of this study is to develop algorithms to estimate land hydrological parameters *i.e.* soil moisture and snow parameters such as snow depth, density, wetness, snow water equivalence (SWE) *etc.* using ALOS data. As first step of this study, we applied existing algorithm to PALSAR data to estimate surface soil moisture.
Soil moisture is a key parameter in numerous environmental studies, including hydrology, meteorology, and agriculture. It plays important roles in the interactions between the land surface and the atmosphere, as well as in the partitioning of precipitation into runoff and ground water storage. In spite of its importance, soil moisture is not generally used for weather forecasting because it is difficult to measure on a routine basis over large areas.
In this paper, 100m-mesh soil moisture maps are derived using PALSAR polarimetry images with existing algorithm. Furthermore, estimated soil moisture values are compared with estimated one by using passive microwave data.

2. PREVIOUS STUDIES

To estimate this important parameter on a large scale, some algorithms were introduced by using brightness temperature data from the passive microwave radiometer measurements [1], [2], [3], [4]. However, the main drawback of radiometer systems for understanding the effect of land surface hydrological heterogeneity on atmospheric circulation and management of basin-scale water resources is their coarse spatial resolution.
Active microwave remote sensors, in particular Synthetic Aperture Radar (SAR), have the potential of observing surface soil moisture with high spatial resolution on a regional scale [5]. In attempting to use SAR image data to estimate soil moisture, several algorithms have been developed. The signal returned to SAR is known as the backscattering coefficient, which is affected by not only dielectric properties that depend on the soil moisture, but also on surface roughness parameters, vegetation, and other surface characteristics. Previous study has revealed that Shuttle Imaging Radar-B (SIR-B) imagery with a single frequency and single polarization system can only describe the dependence of backscattering coefficients on these surface parameters [6]. Tadono *et al.* (2000) developed an algorithm based on hydrological knowledge, and estimated the soil moisture distribution on the Tibetan Plateau using two seasonal Japanese Earth Resources Satellite-1 (JERS-1) SAR images [7].
Radar backscatter studies became more rigorous with the availability of polarimetric radar data, and more sophisticated algorithms for estimating soil moisture were presented. Oh *et al.* (1992) developed an empirical model to estimate the root mean square (rms) roughness height and soil moisture from the co-polarized ratio (backscattering ratio of HH and VV polarizations) and the cross-polarized ratio (backscattering ratio of cross and like polarizations) over bare soils of different roughness, and moisture conditions were measured by a truck-mounted scatterometer system [8]. Also, Dubois *et al.* (1995) developed a model that only requires measurements of HH and VV polarization at frequencies from 1.5 and 11GHz to retrieve both rms roughness height and soil moisture from bare soil and applied it to the L-band data acquired by both the Airborne SAR (AIRSAR) and Shuttle Imaging Radar-

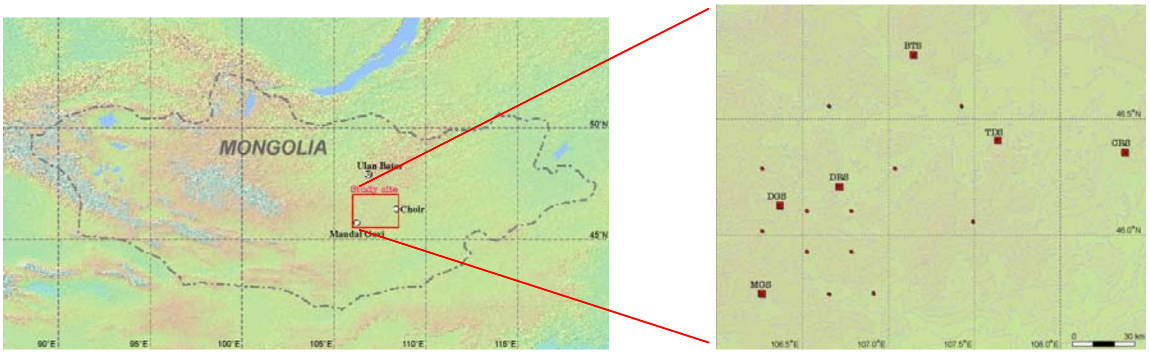
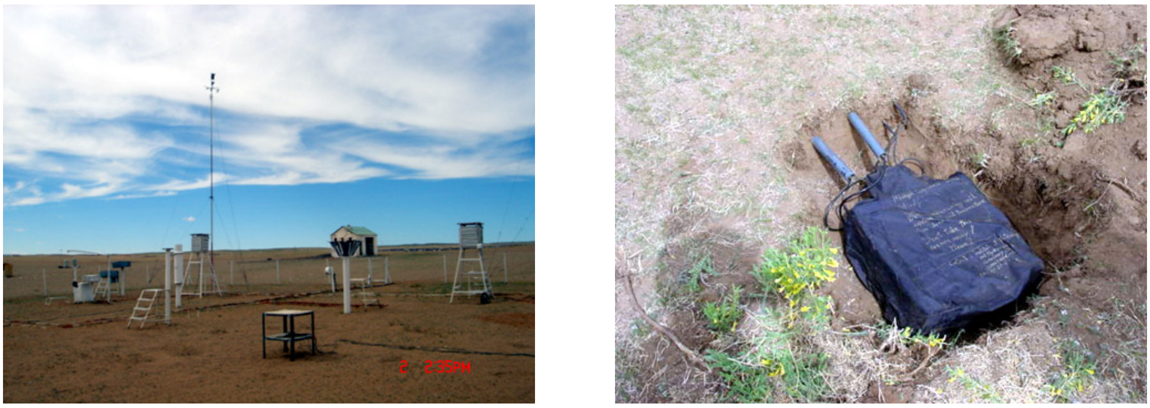


Figure 1. Location of test sites in the Mongolian Plateau (Red squares: AWS sites; red dots: ASSH sites right).



(a) Automatic Weather Station (AWS). (b) Automatic Station for Soil Hydrology (ASSH).

Figure 2. Ground-based measuring systems in the Mongolian Plateau.

C (SIR-C) over a test site in Oklahoma, USA [9]. Hajnsek *et al.* (1999) applied the above two empirical models to L-band data of the airborne Experimental SAR (E-SAR), and compared the performance and accuracy of estimated values [10]. They found that the valid pixels of the E-SAR data decrease to less than 56% of the total number of pixels. Furthermore, soil moisture was underestimated and roughness was overestimated for both models because the regression fits necessary to estimate the roughness and moisture were dependent on the used data sets. Shi *et al.* (1997) pointed out that neither of the above empirical models considered the surface power spectrum [11]. In addition, these empirical models developed from a limited number of observations might have site-specific problems due to nonlinear responses of backscattering to the soil moisture and surface roughness parameters. Therefore, an algorithm based on the single-scattering Integral Equation Method (IEM) was developed to estimate soil moisture and surface roughness from dual-polarized SAR measurements and subsequently applied to both L-band AIRSAR and SIR-C data. Consequently, the rms errors were found to be 3.4% for moisture and 1.9dB for roughness. However, most of these algorithms have been tested at specific test sites, not under diverse natural conditions.

3. STUDY AREA AND DATA

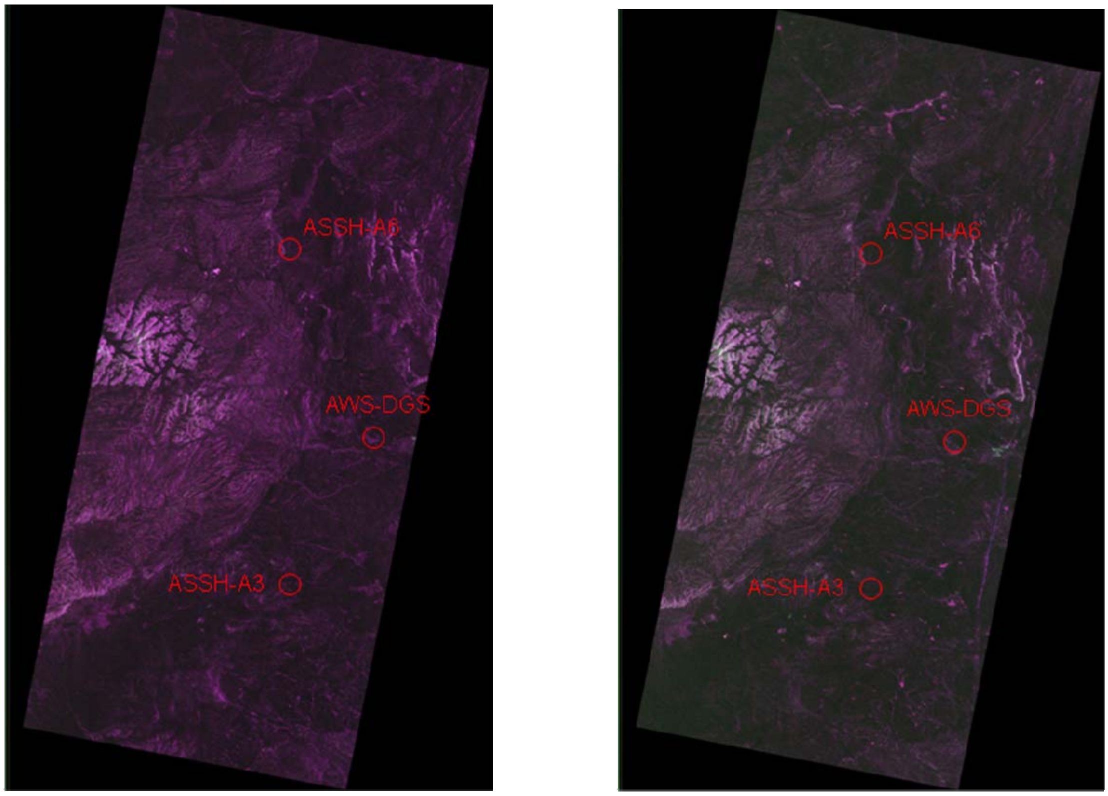
The test sites of this study are located in the Mongolian Plateau, where is spatially homogeneous with basically flat terrain features. Figure 1 shows location of test sites in the Mongolian Plateau, and Figure 2 shows photographs of ground-based measuring systems *i.e.* Automatic Weather Stations (AWSs) and Automatic Stations for Soil Hydrology (ASSH). We are setting up several test sites in southern part of Ulaanbaatar, Mongolia, and installing and maintaining three AWSs and twelve ASSH. Furthermore, we are carrying out intensive experiments in summer seasons.

PALSAR data used in this study were acquired on May 25 and August 25, 2006 by polarimetric mode over AWS site-DGS and ASSH sites-A3 and A6. I expected that these data can be identified seasonal changes of soil moisture during summer season. In winter season in the Mongolia is almost minus degree-C of soil temperature so soil is completely frozen and 0 percentage of soil moisture.

4. SOIL MOISTURE ESTIMATION

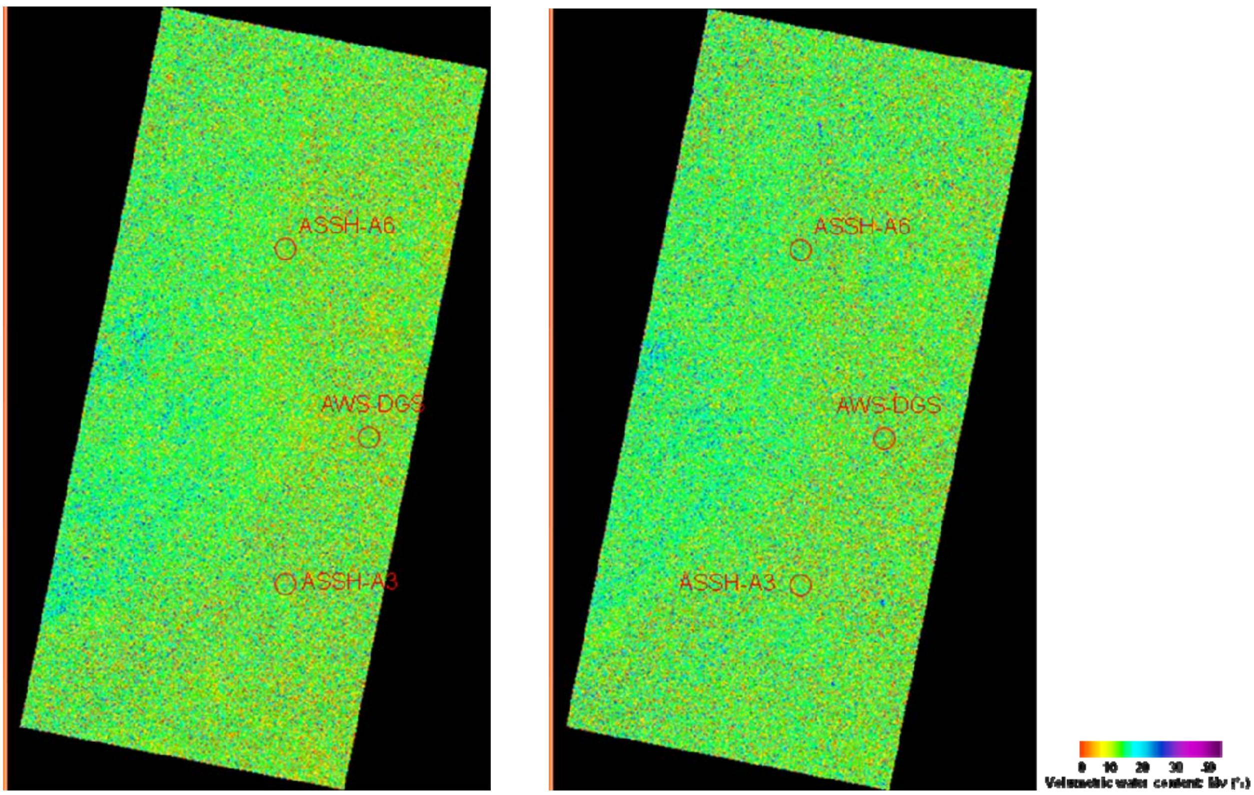
We applied existing algorithm, which is developed by Shi *et al.* 1997 [11] that was based on regression analysis using single scattering IEM model [12] and applied to SIR-C/AIRSAT data. The volumetric water content and surface roughness parameters can be separately retrieved using

$$10\log_{10}\left[\frac{|\alpha_{VV}|^2+|\alpha_{HH}|^2}{\sigma_{VV}^0+\sigma_{HH}^0}\right]=a_{VH}(\theta)+b_{VH}(\theta)\times 10\log_{10}\left[\frac{|\alpha_{VV}|\cdot|\alpha_{HH}|}{\sqrt{\sigma_{VV}^0\cdot\sigma_{HH}^0}}\right] \quad (1)$$



(a) 060525 Descending (ALPSRP017662680). (b) 060825 Descending (ALPSRP031082680).

Figure 3. PALSAR images acquired by polarimetric observing mode (R,G,B=VV,HV,HH).



(a) 060525 Descending (ALPSRP017662680). (b) 060825 Descending (ALPSRP031082680).

Figure 4. 100m-mesh (8x8 pixels averaged) estimated soil moisture maps applied by Shi et al. 1997.

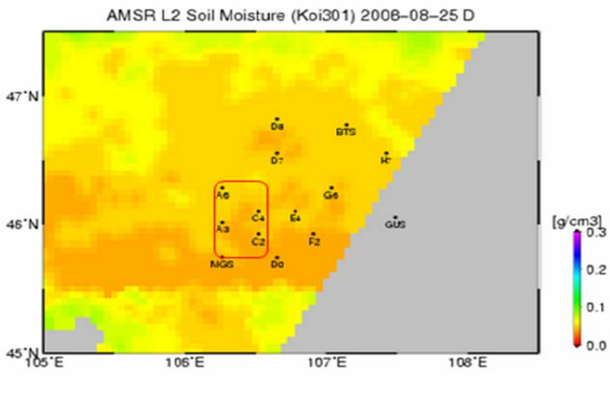


Figure 5. 0.01 degree-grid estimated soil moisture maps on August 25, 2006 derived by AMSR-E.

$$10\log_{10}\left[\frac{|\alpha_{VV}|^2}{\sigma_{VV}^0}\right] = a_{VV}(\theta) + b_{VV}(\theta)\times 10\log_{10}\left[\frac{1}{Sr}\right] \quad (2)$$

where, a: polarization amplitude, k: wave number, J: Bessel function, and coefficients a, b were defined. The validity range of the algorithm is 2 to 50 vol% of soil moisture, 0.2 to 3.6 cm of rms surface height, 2.5 to 35 cm of surface correlation length, 25 to 70 deg. of incidence angle, and exponential, 1.2 power and 1.4 power correlation functions.

5. RESULTS AND DISCUSSIONS

Figure 3 shows browse images of PALSAR observed by polarimetric mode over the test sites on (a) May 25 and (b) Aug. 25, 2006. The red circles indicate location of test sites. Figure 4 show results of soil moisture maps derived from Fig. 3. The retrieval were carried out using original resolution than 8 by 8 pixels corresponding to 100 by 100 meter area averaged soil moisture to reduce effects of speckle noises and uncertainty of inversion processing. The spatial distributions of soil moisture can be identified from Fig. 4 and estimated ranges from 0 to 28 % of soil moisture. The distribution of soil moisture and its characteristics are important in the fields of hydrology and climatology. Figure 4 (b) is looks like more wetter compared with (a) based on qualitatively comparison.

Figure 5 shows estimated soil moisture using AMSR-E passive microwave radiometer onboard AQUA satellite on Aug. 25, 2006. It was derived by algorithm based on [4], and red square indicates location of study area corresponding to Fig. 3. Figure 5 shows averaged soil moisture about 5% over the test site on August. Due to large gaps between both frequencies by PALSAR and AMSR-E, the depths of estimated soil moisture might be different between both estimations in Figs. 4 and 5, especially in the case of dry soil.

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