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To cite this version:

Hongquan Wang, Stéphane Meric, Sophie Allain, Eric Pottier. Monitoring Bare Agricultural Soil: Comparison between Ground Based SAR PoSAR System Measurements and Multi-angular RADARSAT-2 Datasets. EUSAR 2014; 10th European Conference on Synthetic Aperture Radar, Jun 2014, Berlin, Germany. hal-01127977

HAL Id: hal-01127977

https://hal.science/hal-01127977v1

Submitted on 9 Mar 2015

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Monitoring Bare Agricultural Soil: Comparison between Ground Based SAR PoSAR System Measurements and Multi-angular RADARSAT-2 Datasets

Hongquan Wang, Institut National des Sciences Appliquées de Rennes, Hongquan.Wang@insa-rennes.fr, France
Stéphane Méric, Institut National des Sciences Appliquées de Rennes, stephane.meric@insa-rennes.fr, France
Sophie Allain, Université de Rennes 1, sophie.allain@univ-rennes1.fr, France
Eric Pottier, Université de Rennes 1, eric.pottier@univ-rennes1.fr, France

Abstract

The objective of this study is to evaluate the surface roughness and soil moisture effects on polarimetric parameters under multi-incidence angle condition. In order to achieve this objective, we propose to use Ground Based (GB) SAR experiments, in which the specific levels of surface roughness and soil moisture are set deliberately. The results show that image acquired with high incidence angle is more sensitive to surface roughness than that with low incidence angle. Moreover, the results we obtained with our GB-SAR system (called PoSAR for Pocket SAR) are in agreement with the behavior of multi-angular RADARSAT-2 data that we have previously obtained. This indicates that the combination of various incidence angles may help us to improve surface roughness monitoring accuracy and also to get a better estimation of soil parameters.

1 Introduction

Polarimetric SAR provides an opportunity to monitor the spatial and temporal distributions of the soil parameters in both regional and continental scale. The SAR response from bare soil is in functions of target parameters (such as roughness and soil moisture) and system parameters (such as frequency, polarization and incidence angle). Theoretical or empirical models are used to convert the measured backscattering coefficients into surface roughness and soil moisture.

The multi-angular SAR images have potentials to improve the estimation of soil parameters [1]. Multi-angular and multi-polarization configurations were compared in [2], indicating the sensitivity of multi-angular configuration to surface roughness is ten times than multi-polarization, which encourages the continuous exploration of multi-angular inversion models. It was proposed in [1] an original surface roughness parameter to include horizontal and vertical roughness statistical information, and found that backscattering difference between two angular SAR acquisitions depends more on this surface roughness indicator than soil moisture. In addition, [3] suggested to use an additional image acquired under dry condition, which is possible to consider as a unique indicator of surface roughness. As a result, horizontal and vertical roughness can be separated respectively.

Nowadays, operational spaceborne and airborne SAR provide major observational images to monitor soil status. Nevertheless, during the time interval of multi-angular image acquisitions, the surface status (especially soil moisture) may changes. Moreover, it is quite difficult to accomplish all the ground truth measurements over large areas at the same time. These are obvious constraints with currently orbiting radar systems which can not acquire multi-angular images at the same time. To overcome this drawback, the Ground Based (GB) SAR system provides an opportunity to gap the spaceborne and airborne SAR system limitations. It is capable of acquiring multi-incidence angle images in quasi-invariant soil condition.

In this study, we aim to analyze the incidence angle influence on the sensitivity of polarimetric parameters to bare soil. The GB-SAR experiments are analyzed and compared with the behaviors of RADARSAT-2 multi-angular datasets. Section 2 describes the GB-SAR PoSAR experiment and the soil conditions we set up for the measurement. The RADARSAT2 data we used for the comparison are also introduced. In section 3, the angular response of SAR descriptors from the GB-SAR experiment are analyzed and compared with the RADARSAT-2 data obtained under the similar conditions. Finally, main conclusions are presented in section 4.

2 Experiment descriptions

2.1 GB-SAR system measurement

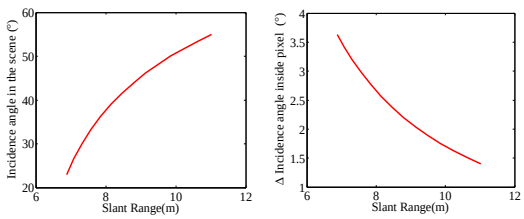
A very high resolution GB-SAR PoSAR system is developed in the IETR [4]. This system is comprised of vector network analyzer, accurate positioning system, antennas, and 3-m rail which undertakes the system. The signal is generated by vector network analyzer in stepped-frequency mode, and then transmitted during system movement which is controlled by the accurate positioning system. The GB-SAR system obtain each line of the image in a stationary state, thus the Doppler centroid is exactly zero. In addition, the value of Doppler rate can be derived by the geometry configuration between the system and target. These accurate estimations of Doppler parameters is essential for signal synthesis. The GB-

SAR PoSAR campaign was carried out on 16 October 2013 over the experimental site of Monterfil (N $48°4'$, E$1°58'$). The system is mounted on a scaffold with height 6.3 m as shown in **Figure 1(a)**. The four antennas from left to right shown in **Figure 1(b)** correspond H, V, H, V polarization respectively. The operating central frequency is set to 5.4 GHz with a 500 MHz bandwidth.

(a) (b)

Figure 1: PoSAR system deployment on scaffold.

The angle of Look Of Sight (LOS) is $38°$ and the beam width in range direction is $30°$. The incidence angle variation within the scene is demonstrated in **Figure 2(a)**.



(a) (b)

Figure 2: GB-SAR PoSAR experiment (a) incidence angle in the scene; (b) incidence angle variation within a pixel.

(a) (b)

Figure 3: (a) Surface roughness SRF measurements; (b) Synchronous samplings using laser and chain.

We will see in the paragraph 2.2 that these incidence angles correspond to the RADARSAT-2 acquisition incidence angles. Nevertheless, due the limitation of platform height, the incidence angle variation inside each pixel (**Figure 2(b)**) is much larger than RADARSAT-2 (the incidence angle variation within full swath is small for RS2). This large variation leads an error in angular response analysis. Although this, the GB-SAR PoSAR system operating parameters are set as much as possible to make the measurements be comparable with RADARSAT-2 images.

Surface roughness was measured by a simple and fast chain approach proposed by [5]. It is based on the justification that when a chain of given length L1 (146.5 cm with 2.2 cm linkage length in our case) is placed straightly along a surface, the covering horizontal distance L2 decreases as surface roughness increases. Therefore, the Saleh Roughness Factor (SRF) is defined as: $SRF = 100(1 - L2/L1)$. This SRF roughness descriptor is used in our study. The SRF was measured 10 times uniformly in two perpendicular directions so as to represent the entire field (**Figure 3(a)**). Moreover, considering the surface roughness is frequently characterized as random roughness factor (s: root mean square height of surface profile) measured using laser/pin roughness meter, a transformation relationship $s(cm) = a\,SRF^b$ is proposed in [6]. The coefficients a and b are in function of rainfall amount [6], and also affected a lot by the linkage length as reported [7]. In our study, the coefficients for roughness scale transformation are derived as $a = 0.5072$, $b = 0.7867$ based on the regression between our measurements using laser and synchronous sampling data using chain approach (**Figure 3(b)**). Based on the original very smooth soil status, three other roughness conditions ($s = 1.6, 2.5, 3.4$) are set by the tillage operation (**Figure 4(a)**).

(a) (b)

Figure 4: Different (a) surface roughness; (b) soil moisture setting up in GB-SAR experiments.

Soil moisture at depth 3.8cm was measured using a calibrated Time Domain Reflectometry (TDR) with samples distributed homogeneously over the test site so as to obtain a representative mean soil moisture value. Two different soil moisture status (22% and 31%) are set by using the Deltalab Microprocessor Controlled Spray System, EID 330 that simulates rain events in still air. Rainfall is simulated by a constant speed oscillating nozzle (Deltalab, Tec Jet SS 6560) at a height of 3.8 m as shown in **Figure 4(b)**.

During each GB-SAR PoSAR operation, $in\ situ$ measurements of soil moisture and surface roughness are implemented, in the similar manner as RADARSAT-2 ground campaign, except for the field dimension here is much smaller.

2.2 RADARSAT-2 data acquisition

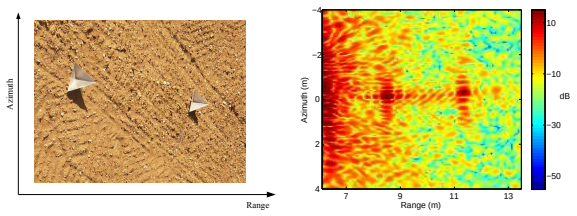
The study agricultural areas using RADARSAT-2 data are located in the site of Pleine-Fougères, near the Mont-St-Michel (N $48°38'$, E$1°30'$) in France. Multi-angular polarimetric RADARSAT-2 images were acquired in April 2013 in fine-quad polarization mode with six incidence angles: 24°, 31°, 33°, 40°, 43° and 49°. The test bare fields are flat and are selected considering their size and their distributions over the common section of multi-angular SAR swaths. *in situ* measurements of surface roughness and soil moisture were carried out in coincidence with the SAR acquisitions over 34 bare fields. As for the GB-SAR campaign, the surface roughness was measured use a simple chain approach and then transformed to conventional roughness descriptor. Moreover, the soil moisture was measured using the same calibrated TDR as in GB-SAR experiments.

3 SAR data analysis

The results we obtained about the sensitivity of GB-SAR PoSAR data to soil characteristics at different incidence angles are presented. Moreover, the behaviors of GB-SAR PoSAR experiment is compared with the findings in RADARSAT-2 datasets [8].

3.1 GB-SAR PoSAR data processing

The received signal is synthesized using back projection algorithm [9] and the basic radar scene which is exhibited in the **Figure 5(a)** is used for calibration (polarimetric and radiometric).



(a) (b)

Figure 5: (a) The trihedral corner reflectors within scene (ridge length=30cm); (b) HH SAR image after synthesizing signal.

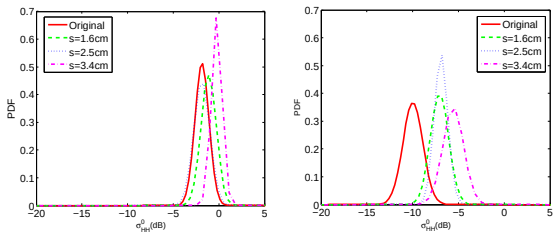
As shown in **Figure 5(b)**, the trihedral corner reflector deployed within the scene is well synthesized. Then the polarimetric calibration is implemented on the synthesized images using approach [10] to remove the cross talk and channel imbalance. Finally, the radiometric calibration is accomplished by calculating the theoretical radar cross section of trihedral corner reflector [11] and comparing with the integral energy of the trihedral within the image.

3.2 RADARSAT-2 data processing

RADARSAT-2 data are extracted as coherence matrix T3 using PolSARpro4.2. A boxcar filter with 7×7 windows is applied to reduce speckle. The polarimetric images are ortho-rectified using NEST.4B (ESA SAR toolbox). Then, the master image is selected from the multi-angular datasets. Other incidence angle images are considered as the slave images and co-registered to the master image. The common section of multi-angular image swath is extracted for further analysis and model development. The half of the pixels inside reference parcels are stochastically selected. Thus, the SAR descriptors are statistically calculated for each study parcel.

3.3 Sensitivity comparisons between PoSAR and RADARSAT-2

For the multi-angular analysis, the PoSAR image pixels located in the same column are considered to have the same incidence angle. The linear backscattering coefficients in HH polarization are analyzed in **Figure 6**, implying the rougher surface s=3.4 cm and the original very smooth surface can be separated from other roughness status. In contrary, the moderate surface roughness s=2.5 cm is confused with the smooth roughness s=1.6 cm. It is noted obviously that at high incidence angle condition, the four roughness status are easier to discriminate than at low incidence angle.

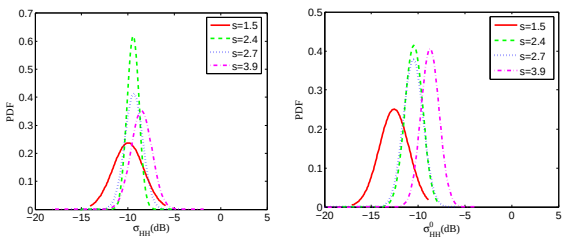


(a) Low $\theta = 24°$ (b) High $\theta = 43°$

Figure 6: Four surface roughness discriminations based on GB-SAR PoSAR data (soil moisture around 30%)

In the same way, four surface roughness status are selected for the RADARSAT-2 study, considering the roughness levels we used in the GB-SAR PoSAR experiment. The discriminations of four roughness status using RADARSAT-2 data at low incidence angle and high incidence angle are shown in **Figure 7**, also indicating that the four roughness fields are easier to be separated at high incidence angle.

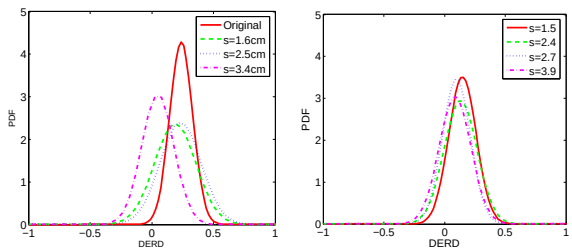
However, we have to notice that the soil moisture is different between the GB-SAR PoSAR experiments and the RADARSAT-2 datasets. Nevertheless, this soil moisture difference does not affect the roughness discrimination ability at high incidence angle (backscattering coefficient is dominated by surface roughness). Thus, the behaviors of GB-SAR PoSAR experiment and RADARSAT-2 data are in accordance with each other, and also agree with the conclusions in [12].



(a) Low $\theta = 24°$ (b) High $\theta = 43°$

Figure 7: Corresponding four surface roughness discriminations based on RADARSAT-2 data (soil moisture around 15%).

Besides the backscattering coefficient, the polarimetric parameter is also used to discriminate different soil status. Based on the difference between double and volume scattering power, a polarimetric parameter DERD is defined in [13] to characterize the surface roughness. It is shown in **Figure 8** the separation among four roughness status using GB-SAR and RADARSAT-2 measurements. The DERD decreases with surface roughness in two cases, and the GB-SAR data is more robust to discriminate the surface roughness.



(a) GB-SAR (b) RS2

Figure 8: Polarimetric parameter DERD comparison.

4 Conclusions and perspectives

In this study, the sensitivity of GB-SAR measurement to soil characteristics are evaluated under different incidence angles and compared with the findings we obtained using RADARSAT-2 multi-angular datasets. By using the GB- SAR PoSAR system, the multi-angular polarimetric SAR data can be obtained in a quasi-invariant soil condition, which is an indispensable assumption for multi-angular inversion model. Furthermore, different surface roughness and soil moisture condition can be set deliberately, which is superior to field-scale spaceborne SAR conditions. The results we obtained using our GB-SAR PoSAR measurement indicate that at higher incidence angle, the backscattering signature is more dominated by surface roughness. The polarimetric parameter (such as DERD [13]) has the potential to discriminate roughness at high incidence angle. This angular response pattern in GB-SAR PoSAR measurements is in accordance with RADARSAT-2 datasets.

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