POLARIMETRIC DECOMPOSITION OF MULTI-ANGULAR SAR DATA FOR SOIL MOISTURE RETRIEVAL OVER AGRICULTURAL FIELDS

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ABSTRACT

This study investigates the polarimetric decomposition of multi-angular polarimetric UAVSAR (Uninhabited Aerial Vehicle Synthetic Aperture Radar) time series, for soil moisture retrieval over the vegetated agricultural fields. The volume scattering component was respectively removed from different incidence angle data. The resulting multiple dominant surface or dihedral scattering components were then integrated as a multi-angular cost function, from which the soil moisture was retrieved. The retrieval performances of single-angular and multi-angular methods were compared, and validated with the ground measurements. The results indicated that, due to the incidence angle combination, the retrieval RMSE decreased, and the level depends on the phenological stage. A significantly high retrieval rate of 90% can be obtained by the multi-angular approach, compared to that of 50% in the single-angular method.

Index Terms- Soil moisture, agricultural fields, multi-angular, polarimetric decomposition, SMAPVEX12.

1. INTRODUCTION

The sensitivity of remote sensing signal to the geophysical parameters highly varies, when the incidence angle changes. Several effort of signal normalization to a constant incidence angle was conducted in the past [1]. However, the importance of incidence angle diversity was also realized. For instance, the BRDF (Bidirectional Reflectance Distribution Function) accounted for the variation of the radiation due to the change in the incident beam and in the sensor observation angle [2].

For soil moisture retrieval with multi-angular approaches, several efforts were devoted, but mainly considering the bare soil. The behaviors of multi-angular and multi-polarization methods for soil moisture retrieval were compared in [3], indicating that the multi-angular SAR observables are more sensitive to soil parameters than the multi-polarization. Furthermore, the merits of multi-angular approach were highlighted in [4], indicating a significant increase in correlation coefficient, and a decrease in the RMSE, when comparing the retrieved soil moisture with the ground measurement. These efforts encouraged us to study the polarimetric parameters under multi-angular condition for soil moisture retrieval over vegetated agricultural fields. In such a way, the information dimensions of both the polarimetry and incidence angle can be fully integrated. Indeed, a scheme of polarimetric decomposition of multi-angular SAR data was previously proposed in [5], illuminating the potential of incidence angle diversity to improve the soil moisture retrieval. Nevertheless, the performance of dihedral scattering component was limited, due to the insufficiently compensation of microwave propagation effect. Particularly, for incidence angle around 45°, the soil moisture retrieval is ambiguous, as a result of the coupling between soil and crop dielectric constants.

In order to deepen our insight in the multi-angular polarimetric approach, this study investigates the surface and dihedral scattering components derived from UAVSAR (Uninhabited Aerial Vehicle Synthetic Aperture Radar) time series, for soil moisture retrieval over vegetated agricultural fields. The dataset acquired in the framework of SMAP Validation Experiment 2012 (SMAPVEX12) were used for the analysis and retrieval.

2. METHOD

This study developed and validated a multi-angular soil moisture retrieval approach, which was based on an existing polarimetric decomposition [6]. For each single-angular data, the full coherency matrix was modeled as the incoherently summation of three submatrices [6]:

$$[T3]=\begin{bmatrix} T_{11} & T_{12} & 0 \\ T_{12}^* & T_{22} & 0 \\ 0 & 0 & T_{33} \end{bmatrix} = f_s \begin{bmatrix} 1 & \beta^*\mathrm{sinc}(2\delta) & 0 \\ \beta\mathrm{sinc}(2\delta) & \frac{1}{2}|\beta|^2(1+\mathrm{sinc}(4\delta)) & 0 \\ 0 & 0 & \frac{1}{2}|\beta|^2(1-\mathrm{sinc}(4\delta)) \end{bmatrix} + f_d|L_s|^2 \begin{bmatrix} |\alpha|^2 & \alpha & 0 \\ \alpha^* & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} + f_v \begin{bmatrix} V_{11} & V_{12} & 0 \\ V_{12} & V_{22} & 0 \\ 0 & 0 & V_{33} \end{bmatrix} \quad (1)$$

The first term, as surface scattering component, is simulated by a surface intensity coefficient f_s and X-Bragg model. The β is a function of the soil dielectric constant and the incidence angle, and δ governs the surface roughness. The second term, as the dihedral component, is modeled by a dihedral intensity coefficient f_d, a wave propagation term L_s, and Fresnel coefficient α. The third term, as the volume scattering component, is modeled with a volume scattering intensity coefficient f_v and predefined volume coherency matrix as dipoles with thee orientations. The trace of the individual component is the corresponding scattering power.

In our study, the four coherency matrices $[T3]_{\theta i}$ ($\theta_1<\theta_2<\theta_3<\theta_4$) were extracted from different flight lines using the PolSARpro5.0 software. For each flight line, the crop orientations were determined using the ratio index of backscattering coefficients in VV and HH polarization. Depending on the ratio, one of the three predefined volume coherency matrix was assigned to simulate the volume scattering component. As for the volume intensity f_v, two volume scattering intensity values (f_{v1}, f_{v2}) were computed by solving Eq. (1). Meanwhile, three values (f_{v3}, f_{v4}, f_{v5}) were extracted by solving the equation, when setting the eigenvalue of the ground component to zero. The minimum of f_{vi} (i = 1 to 5) was finally chosen as the appropriate f_v, to overcome the problem of negative Eigen values [7].

Importantly, for the case of dominant surface scattering in the ground component, multiple values of β were obtained for each pixel. Consequently, a cost function in Eq. (2) was established to achieve the retrieval of soil moisture. In this way, as in [4] on the backscattering coefficient, both the retrieval rate and accuracy were expected to be improved, compared to the performance of single-angular acquisition.

$$c_s = \sqrt{\left|\beta_{\theta 1}^{simu} - \beta_{\theta 1}^{data}\right|^2 + \left|\beta_{\theta 2}^{simu} - \beta_{\theta 2}^{data}\right|^2 + \left|\beta_{\theta 3}^{simu} - \beta_{\theta 3}^{data}\right|^2 + \left|\beta_{\theta 4}^{simu} - \beta_{\theta 4}^{data}\right|^2} \quad (2)$$

In the former studies [5, 6], the soil moisture retrieval from the dihedral component was based on a cost function, comprised of f_d and α. However, considering the difficulty to properly compensate the effect of microwave propagation power loss on f_d, the performance of dihedral component was less promising than that of surface component. Therefore, to overcome this limitation, this study developed a different cost function in Eq. (3) by using multiple values of α, since the ratio formulation of α is more robust than the absolute intensity f_d.

$$c_d = \sqrt{\left|\alpha_{\theta 1}^{simu} - \alpha_{\theta 1}^{data}\right|^2 + \left|\alpha_{\theta 2}^{simu} - \alpha_{\theta 2}^{data}\right|^2 + \left|\alpha_{\theta 3}^{simu} - \alpha_{\theta 3}^{data}\right|^2 + \left|\alpha_{\theta 4}^{simu} - \alpha_{\theta 4}^{data}\right|^2} \quad (3)$$

Finally, the retrieval results from the dominant surface and dihedral component were integrated.

3. EXPERIMENTAL DATA

As shown in Fig. 1, the study area was one part of the agricultural site involved in the SMAPVEX12 campaign, located in Winnipeg (Manitoba, Canada). The study area mainly contained agricultural fields, while some portions were also covered by pasture and forest. The main annual crops here include canola, corn, soybean and wheat, which will be studied. The topography here is very flat, allowing better analysis of soil moisture distribution pattern, without significant disturbance from the topography. As more details on the SMAPVEX12 campaign as well as collected dataset can be found in [8] and the SMAPVEX 12 website (https://smapvex12.espaceweb.usherbrooke.ca/), only the pertinent elements are concisely described.

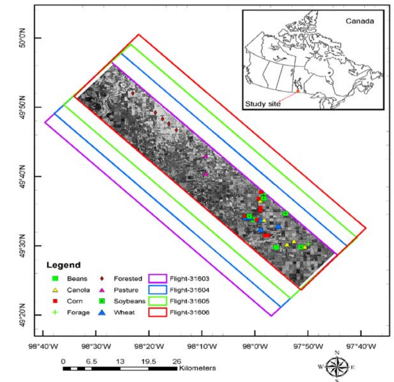

Fig. 1. Agricultural fields covered by UAVSAR multi-angular observations.

The L-band polarimetric UAVSAR time series were acquired on 14 days from June 17 to July 17, 2012. On each acquisition day, four flight lines, namely #31603(θ_1), #31604(θ_2), #31605(θ_3) and #31606(θ_4) were conducted in the same flight direction of northwest. They formed a multi-angular SAR observation for 22 agricultural fields out of total 55 fields, where ground measurements were collected during the SMAPVEX12 campaign. In the current study, we considered the flight line #31606 as master image, to which other three flight lines were co-registered.

The soil moisture was measured at 5-cm depth using TDR. In order to know the environmental condition for the multi-angular image acquisitions and ground measurement, the precipitation information was collected. A pronounced dependence of soil moisture on the precipitation was found [9]. Furthermore, the measurements of the soil moisture were always performed on the same day as the UAVSAR acquisition, offering a good opportunity to interpret the polarimetric SAR data in terms of the ground measurements.

Surface roughness measurements were conducted only once during the campaign. The measured roughness (ks <0.62, with wavenumber k and RMS height s) satisfied the physically requirement of X-Bragg (ks <1), which was used to model the surface scattering component in Eq. (1).

To examine the influence of vegetation on the soil moisture retrieval, the crop growth parameters such as height, biomass and vegetation water content were continuously collected during the campaign. These crop parameters allowed the analysis of the temporal evolution of scattering mechanisms, especially for the volume scattering mechanism.

4. RESULTS DISCUSSION

4.1. Incidence angle effect on scattering mechanism

Fig. 2 show the temporal evolution of the scattering powers, considering the corn as an example, for the entire period of SMAPVEX12 campaign. The temporal profiles of the scattering powers derived from the four incidence angle data follow a very similar variation trend, but to different absolute power values. For a given day, the surface

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