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Active/Passive Remote Sensing of a Mature Soybean Canopy at L-band

Yiwen Zhou[(1),(2)], Roger Lang[(1)], Avinash Sharma[(1,3)] and Peggy O'Neill[(4)]

(1) The George Washington University, Washington, DC, 20052, USA
(2) Lincoln Agritech Ltd., Lincoln University, Christchurch, 7674, New Zealand
(3) Applied Physics Lab, The Johns Hopkins University, Laurel, MD, 20723, USA
(4) NASA Goddard Space Flight Center, Greenbelt, MD, 20771, USA

Abstract

This paper reports on development of a scattering model of a soybean canopies at L-band. The scattering model will be used for active and passive remote sensing of soybean plants with an emphasis on mature soybeans where the presence of pods is important to the observed microwave signal. The active problem is treated using the Distorted Born Approximation (DBA) and the passive problem is analyzed using Peake's method. These results are compared with field measurements made in 2012 by the truck-mounted ComRAD system, which is a combined radar and radiometer instrument operating at L-band. Investigation of backscatter from the soybean canopy shows good agreement between the radar measurement data and modeling results. The results also indicate that the L-band radar backscatter can be used to monitor both the soil moisture and the growth of the soybean pods. Past passive modeling efforts have not considered soybeans late in the growing season when pods are important. A new passive radiation model of soybean canopy will be developed based on the backscatter model.

1 Introduction

L-band satellites have been widely used to sense the land remotely [1], [2]. An accurate model for calculating the scattering from a layer of vegetation can be useful for retrieving soil moisture and monitoring vegetation dynamics from satellite data.

In the past, very few studies have modeled a crop canopy when it reaches the reproductive stage and produces fruit, even though a significant amount of biomass can be attributed to the fruit itself, as shown in [3], [4]. Studies that do include the fruit contributions are typically modeled using simple canonical shapes such as dielectric discs and cylinders [5], [6]. In this paper, the development of an accurate scattering model for a soybean canopy is presented. The soybean pods are carefully modeled to determine their contribution to the overall scattering from a soybean canopy.

A typical model used for a soybean canopy consists of a sparse layer of randomly located discrete scatterers over a dielectric half-space, having a rough underlying surface. Soybeans leaves are modeled by thin dielectric discs, whose scattering can be solved analytically [7]. Since the soybean pods appear in bunches along a stem, they are difficult to model analytically. As a result of this complexity, the pods and stem are modeled together by a commercial EM solver [8]. The pods-stem and leaves are assumed to be independent of each other. The numerical method allows for a more realistic and accurate modeling.

Soil Moisture Active Passive (SMAP) is a NASA satellite launched in 2015 [2] that measures soil moisture remotely with a combined radar and radiometer instrument. The radiometer operates at 1.41 GHz and the radar operates at 1.25 GHz. Although SMAP's radar stopped working 5 months after launch, the radiometer has continued to provide valuable data for land mapping up to the present time. To simulate data from the SMAP mission, the Combined Radar and Radiometer (ComRAD) instrument system was developed by George Washington University and NASA/GSFC [9]. ComRAD contains both a radar and a radiometer operating at the same frequencies as SMAP. ComRAD measurements were taken of a soybean canopy over the full growing season in 2012. These measurements will be presented at the meeting to validate the scattering model for soybean plants.

In this paper, section 2 will briefly introduce the soybean in situ measurements and ComRAD field experiment. The scattering model and its application on active remote sensing will be presented in section 3. The approach to model passive radiation of the canopy will be discussed in section 4. Finally, the conclusions will be drawn in section 5 and the reference will be given in section 6.

2 Soybean Measurements

In situ measurements of the soil and soybean plants were taken in a field, owned by US department of Agriculture, located in Beltsville, MD, USA over the whole growing season in 2012. Vegetation ground-truth data collected included the soybean canopy height, the dimensions of leaves, pods and stems, the number of leaves and pods per plant and the permittivity of soybean pods. The Vegetation Water Content (VWC) of soybean components was also measured by weighting the sample before and after oven-drying to a constant weight. The data are documented in

Figure 1. ComRAD instrument system

[8]. These measurements showed that soybean pods became thicker in the late stages. In addition, the VWC of soybean plants stayed relatively consistent over the reproductive stage.

ComRAD is a SMAP simulator (see Fig.1), containing both an L-Band radar and radiometer mounted on a 19 m high boom. The antenna used is a parabolic dish antenna with a Cassegrain-like feed. The feed is implemented with a circular waveguide that has two orthogonally placed wire probes, one to support horizontal polarization and the second to support vertical polarization. For this study, the system measured the scene with an incident angle of 40° over an azimuth range of 120°. The radar measurements have been taken every 2° in azimuth so in total 60 independent measurements have been made by the radar during in each scan; the radiometer also made measurements at 5-7 separate locations within the same 120º azimuthal range during each measurement series. The ComRAD radar data is plotted in Fig. 2 as a function of Day of Year (DOY) [8].

Figure 2 delivers two important messages. First, there is a strong correlation between Volumetric Soil Moisture (VSM) and radar backscatter, raining events are precisely reflected on backscatter. Another interesting thing to note is that the difference between HH-pol and VV-pol backscatter becomes greater as DOY increases. This is probably due to the soybean plants become more mature and thus the soybean pods grow thicker, as DOY becomes larger. The increasing difference between HH-pol and VV-pol backscatter can be due to the growing contribution from soybean pods. To examine this assumption and explore the relationship between soybean canopy and polarimetric radar backscatters, a backscatter model of soybean canopy has been developed.

3 Backscattering Model of Soybean Canopy

The Distorted Born approach is used to develop a coherent backscatter model of soybean plants in this study. The model consists of a sparse layer of randomly located discrete scatterers over a dielectric half-space having a

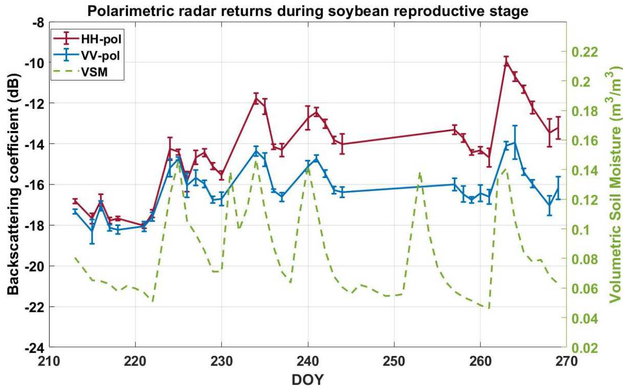

Figure 2. ComRAD data as a function of DOY [8]

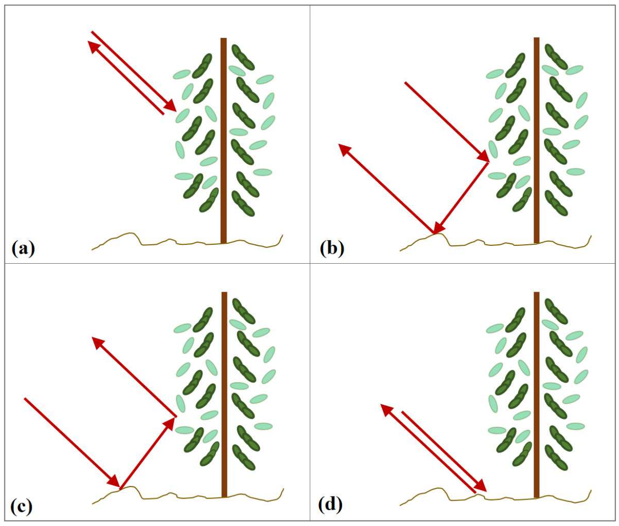

Figure 3. Types of Scatter Contributions: (a) direct backscatter from the vegetation scatterer, (b-c) direct-reflected backscatter from soybean-soil, (d) direct backscatter from the soil.

rough surface. Four different types of backscatter are shown in Figure 3. Figure 3(a) is the direct backscatter from the scatterers. Figure 3(b) and 3(c) represent direct-reflected backscatter. In this case the waves are scattered by ground and the scatterers in the canopy layer. These two direct-reflected backscatters travel the same paths but in opposite directions. Since they have the same phase, they add coherently resulting in double the contribution for like polarization. Finally, Figure 3(d) represents the direct backscatter from the rough surface of the soil. The total backscatter of the canopy is the sum of these four types of backscatters.

To develop the coherent backscatter model, the scattering amplitudes of the scatterers in canopy layer need to be determined. The main contributors are leaf, pod and stem. In this study, the soybean leaf is approximated by an elliptical disc and modeled using the analytic method developed in [7]. Since soybean pods are usually clustered around stems (see Fig. 4(a)), the pod clusters and stem form a more complex scatterer that is difficult to be modeled by the analytic method. Therefore, we developed a realistic soybean pods-stem model and used numerical method to solve its scattering amplitude in FEKO (a commercial EM

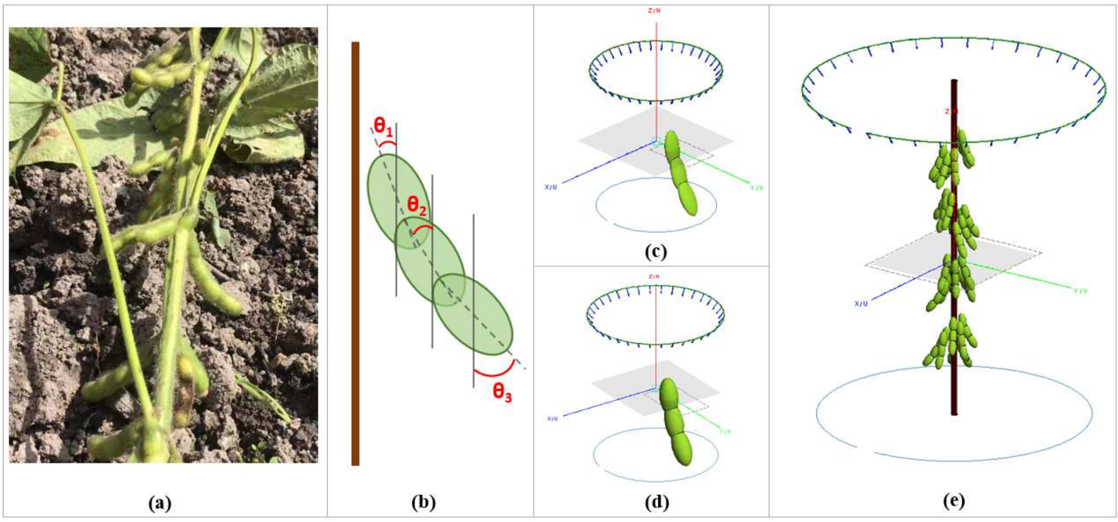

Figure 4 Scattering model of soybean pods and stems in FEKO [(a) soybean pods picked from the field; (b): illustraton of pods modelling; (c) and (d): single pod model at beginning-seed and full-seed stage, respectively; (e): pods and stem model at full-seed stage]

solver). Each soybean pod is modelled by three ellipsoidal dielectric scatterers, representing the beans in the pod [8]. The beans within each pod are close to each other and are increased in size slightly to account for the pod shell. The soybean pods are positioned close to the stem in bunches of three at various distances along the stem. The thickness of pods is set to be a variable that is dependent on DOY, i.e. the reproductive stages of soybean plant. Fig.4(c) and (d) shows a single pod model at beginning- and full- seed stage, respectively, and Fig. 4(e) shows a full pods-stem model. The scattering amplitudes of the FEKO computation are then imported into a Matlab backscatter program. The scattering amplitudes of leaves and the pods-stem, together with their density, can then be used in the coherent scattering model developed in [10] to obtain the backscatter from the soybean plants.

The ground is modeled by the measured RMS height and correlation length. The backscatter due to the rough surface is predicted using the Small Perturbation Method [11]. The contribution of the soil surface can then be added to the coherent scattering model to compute the total backscatter from the soybean canopy.

The backscattering coefficients are computed for the case when the soybean pods are present and for the case when there are no pods during the full growing season. The results are compared with the radar data, see Fig. 5. It has been found that the soybean-pod model has much stronger correlation with the measured data compared with the no-pod model [8]. For the soybean-pod model, the R coefficient between the model and data is about 0.78 for VV-pol and 0.52 for HH-pol. For the no-pod model, the R coefficient is 0.56 for VV-pol and -0.31 for HH-pol. The negative number indicates that the behavior of the no-pod model is opposite to that of the measured data. The difference between HH- and VV-pol backscatter is also strongly correlated with pod size and number [8]. The number of pods per plant can be estimated by the difference between the backscattering coefficients of HH- and VV-pol.

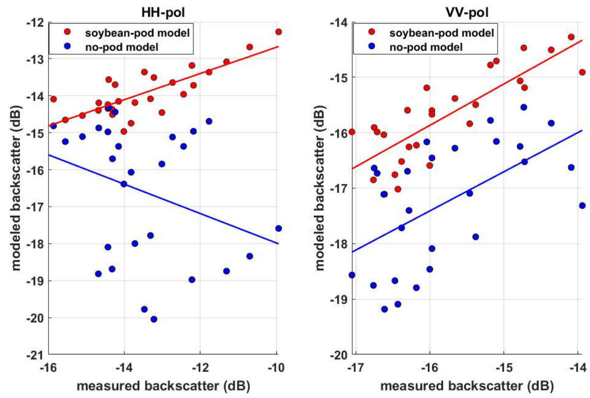

Figure 5 Correlation between the measured and modeled backscatter [8]

4 Passive Remote Sensing of Soybean Canopy

The Peake method [12] relates the passive radiation, i.e. emissivity, to radar backscatter. This method is used to compute the brightness temperature of the soybean canopy. If unit incident power is assumed, then the power scattered by the surface (ground) and the power transmitted into the surface must sum to one. Employing the model and methodology introduced before, the scattered power can be calculated. The power absorbed is one minus the scattered power which by the Kirchhoff principle is equal to the emissivity, and thus the brightness temperature can be obtained.

Based on this method, the polarized emissivity observed from the direction (θ_0, ϕ_0) can be obtained by [12]:

$$
\begin{aligned}
e_h(\theta_0,\phi_0) &= 1-\frac{1}{4\pi\cos\theta_0}\cdot\int\big[\sigma^0_{hh}(\theta_0,\phi_0;\theta_s,\phi_s) \\
&\quad +\sigma^0_{hv}(\theta_0,\phi_0;\theta_s,\phi_s)\big]d\Omega_s, \\
e_v(\theta_0,\phi_0) &= 1-\frac{1}{4\pi\cos\theta_0}\cdot\int\big[\sigma^0_{vv}(\theta_0,\phi_0;\theta_s,\phi_s) \\
&\quad +\sigma^0_{vh}(\theta_0,\phi_0;\theta_s,\phi_s)\big]d\Omega_s,
\end{aligned} \tag{1}
$$

where h and v are polarization types, (θ_s,ϕ_s) is the direction of scattered power, Ω_s is solid angle and the integration is carried over the upper hemisphere. The brightness temperature can then simply be obtained by:

$$
T_{bh}=e_h\cdot T \quad \text{and} \quad T_{bv}=e_v\cdot T \tag{2}
$$

where T is the physical temperature.

By employing Peake's approach, all the methodologies developed for the radar backscatter can be employed to make the passive calculation. The calculated results will be compared with ComRAD radiometer data and the sensitivity of passive and active results to the presence of soybean pods will be explored.

5 Conclusion

An analysis of radar backscatter and passive radiation from a soybean canopy has been made with an emphasis on the reproductive stages. Modeled results have been compared to measured ComRAD data from a 2012 field experiment. Both modeled and measured results show that the presence of soybean pods has an effect on backscatter of soybean canopy. An important finding is that the difference between the HH- and VV- pol backscatter is strongly correlated to the thickness and the density of soybean pods. Therefore, polarimetric L-band radar backscatter can be used to monitor the development of soybean plants. We are currently exploring the effect of soybean pods on radiometric measurements and models.

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