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SPATIAL VARIABILITY IN MICROWAVE RADIOMETRIC SIGNATURES OF GROWING CORN AND SOYBEAN DURING SMAPVEX16-MICROWEX

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ABSTRACT

In this study, the impact of spatial variability due to the heterogeneity of vegetation in the agricultural region on passive microwave signatures available at various scales are explored using the brightness temperature (T_B) observed from ground, air, and space. These observations were conducted during a growing season of corn and soybean in South Fork watershed, Iowa, as part of the NASA-Soil Moisture Active Passive Validation Experiment (SMAPVEX16). Both empirical and physically-based microwave emission models are used to understand the effects of vegetation on T_B for corn and soybean using ground-based T_B observations. The modeled T_B will be upscaled based upon the USDA crop layer map to compare with the T_B observed in the coarse scales.

Index Terms—Soil Moisture, Passive Microwave Remote Sensing, Scale Variability, Vegetation Opacity.

1. INTRODUCTION

Soil moisture (SM) is one of most dominant factors in land surface-vegetation-atmosphere processes. In agriculture, accurate estimation of the SM is essential for modeling and predicting the growth and yield of crops [1]. Microwave remotely sensed observations, particularly at frequencies <10GHz, is very sensitive to the water content in the soil due to large difference between the dielectric constant of dry and wet soil. The current satellite-based SM missions, including European Space Agency (ESA) Soil Moisture Ocean Salinity (SMOS) and National Aeronautics and Space Administration (NASA) Soil Moisture Active Passive (SMAP) missions, have provided passive microwave observations at 1.41GHz (L-band) for global SM mapping at the spatial resolution of 25-40 km, with a repeat coverage of 2-3 days [2].

The performances of SM retrieval and assimilation algorithms using passive microwave observations rely on realistic estimates of brightness temperatures (T_B) from the microwave emission algorithms. With the increase of the vegetation canopy during the growing season, attenuation and scattering within the canopy increases, complicating modeling of the canopy contribution and may result in inaccurate SM estimation [3,4]. Moreover, the effects due to diversity of vegetation are not well understood, and may result in errors in the current up/down-scaling T_B algorithms under heterogeneous, vegetated landscapes, such as the agricultural regions [5].

The goal of this study is to investigate the impacts of vegetation on the microwave signatures at different spatial scales. The development and validation of these algorithms require concurrent field observations of microwave signatures along with measurements of *in-situ* SM and vegetation parameters. This study uses microwave and *in-situ* soil and vegetation observations from Microwave and Water Balance Experiment, conducted as part of the NASA SMAP Validation Experiment 2016 (SMAPVEX16-MicroWEX). The objectives of this study are to 1). explore the effects of vegetation parameters on the current emission models during growing season of corn and soybean, and 2). understand the effect of heterogeneity of crop types on different scales of microwave observations. This study will showcase the insights into microwave emission modeling in the vegetated fields and the impact of vegetation heterogeneity on the up/down-scaling algorithms.

2. STUDY REGION AND DATASET

2.1 SMAPVEX16-MicroWEX

This study uses observations during the SMAPVEX16-MicroWEX conducted in the Sweeney Farm, Alden, Iowa by the Center for Remote Sensing, Institute of Food and

Fig. 1. The field layouts of corn and soybean fields.

Agricultural Sciences, University of Florida. Similar to the Microwave Water and Energy Balance Experiments (MicroWEXs) conducted in North-Central Florida since 2003, e.g. [6], the experiment was primarily to monitor active and passive microwave signatures of bare soil and growing vegetation. During the SMAPVEX16-MicroWEX, the ground-based microwave and *in-situ* soil and vegetation observations were conducted in two 75m x 50m fields for observing the microwave signatures of growing corn and soybean from May 4 (Day of Year, DoY 125) to September 7 (DoY 251), respectively. The field layouts are shown in Fig 1. The predominant crops in the study region are corn and soybean with a rainfed agricultural system. The soil texture in the study region is silt loam with 29% of clay, 11% of sand, and 60% of silt based upon the USDA Soil Survey.

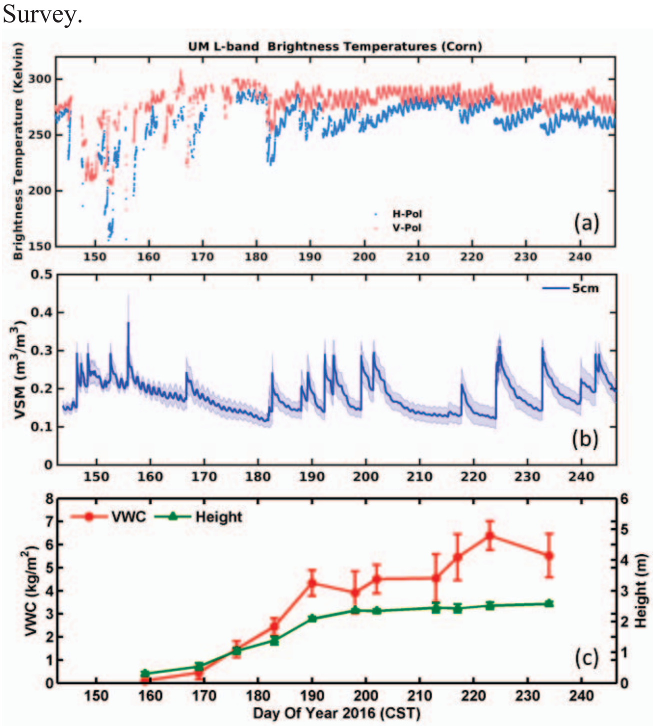

Fig.2 Observations of (a) T_B at dual-pol, (b) SM at 5 cm, and (c) VWC and crop height of corn during the SMAPVEX16-MicroWEX.

2.2. Ground-Based Observations

During the experiment, the ground-based passive microwave observations were conducted using the University of Michigan L-band Microwave Radiometer (UM-LMR) and the University of Florida LMR (UF-LMR) for corn and soybean fields, respectively. The UM- and UF-LMR, built by the Microwave Geophysical Group at UM based upon the same design, were operated at the central frequency of 1.41 GHz to observe the microwave emission of dual-pol and H-pol, respectively every 15 mins, with the incidence angle of 40^o, coincident to the SMAP. Such a dataset at high temporal resolution allows for a better understanding of the sensitivities during dynamic moisture and vegetation conditions.

The *in-situ* volumetric soil moisture (VSM) and soil temperature values in the both fields were observed using Time Domain Reflectometry (TDR) probes and thermistors, respectively, at depths of 5, 10, 15, 30, 60 and 120cm. Two rain gauges in each field were used to record the water input during the precipitation events. The fields were disked and planted using a multirow cultivator to make the surface roughness and the seed, hence, the vegetation density uniform in the fields. Weekly destructive vegetation samplings were conducted including measurements of leaf area index, biomass, canopy height, and vegetation water content (VWC) over the seasons. Fig. s and 3 show observed T_B at dual and H-pol in corn and soybean fields, respectively, VSM at 5 cm, and the VWC and plant height during the experiment.

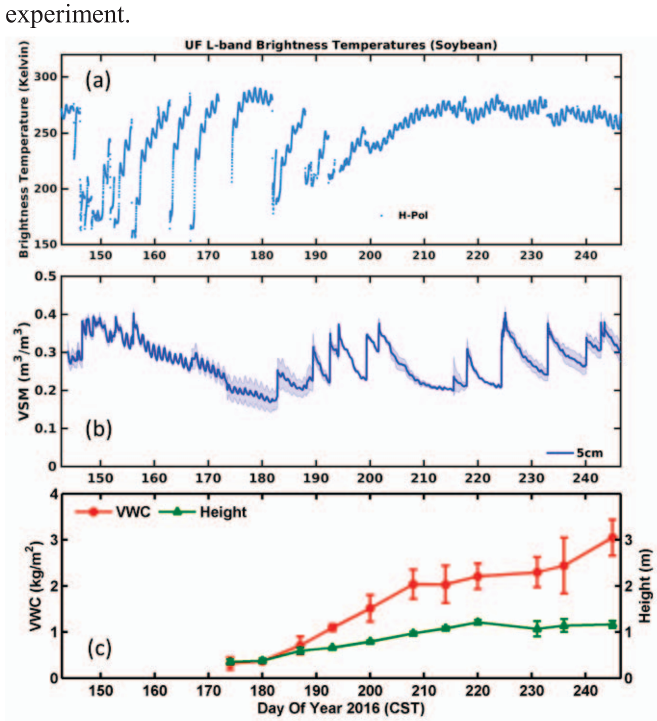

Fig.3 Observations of (a) T_B at dual-pol, (b) SM at 5 cm, and (c) VWC and crop height of soybean during the SMAPVEX16-MicroWEX.

Soil roughness measurements, including root mean square height (s) and correlation length (cl), were conducted by the Department of Agronomy at Iowa State University, using LiDAR on DoY 146, when the fields were nearly bare soil. The mean s and cl were 1.8 and 9.9cm, respectively, in the corn field, and 1.6 and 12.0cm, respectively, in the soybean field.

2.3. Satellite- and Airborne-Based Observations

The agricultural land cover map from the MODIS is used in conjunction with the USDA-National Statistics Survey crop data layer (USDA-CDL) to understand the crop distribution in the region. The aerial-based T_B observations at the spatial resolution of 800m conducted by NASA JPL using the Passive Active L- & S-band (PALS) sensor during the two Intensive Observation Periods (IOPs; May 25-June 5 and August 3-16) were used as the intermediate scale of observations. Meanwhile, the NASA-SMAP L2 T_B product at the spatial resolution of 36km and the ESA-SMOS L3 T_B product at the spatial resolution of 25 km over the entire growing season are used as the coarse scale of observations.

3. MICROWAVE MODELING

3.1 Microwave Emission Model

The microwave emission model estimates T_B contributions from soil ($T_{Bsoil,p}$), vegetation ($T_{Bveg,p}$), and sky ($T_{Bsky,p}$) in the vegetated field, given as [4]:

$$T_{B,p} = T_{Bsoil,p} + T_{Bveg,p} + T_{Bsky,p} \quad \text{(1a)}$$

$$T_{Bsky,p} = T_{sky} r_p \exp(-2\tau \sec\theta_0) \quad \text{(1b)}$$

$$T_{Bsoil,p} = T_{eff}(1 - r_p)\exp(-\tau \sec\theta_0) \quad \text{(1c)}$$

$$T_{Bveg,p} = T_c\left[1 - \exp(-\tau \sec\theta_0)\right](1-\omega)\times \left[1 + r_p \exp(-\tau\sec\theta_0)\right] \quad \text{(1d)}$$

where, the subscript p is the microwave polarization (V- or H-pol), T_{sky} is the downwelling sky brightness at about 5K for L-band, T_{eff} is the effective temperature of the soil, defined as an integral of radiative temperature over non-isothermal soil layers, r_p is the soil reflectivity, and (1-r_p) refers to soil emissivity (e_p), τ is the optical thickness of vegetation, θ_0 is the incidence angle, T_c is the physical temperature of canopy, which is assumed isothermal and close to the air temperature in the field, and ω is the single scattering albedo of canopy. The following subsections describe the models in detail.

3.2. Microwave Signature of Soil

The soil is a non-isothermal, semi-infinite layered medium, with a rough surface at the upper boundary. In the study, the Advanced Integrate Emission Model (AIEM) [7] is used to obtain the emissivity of the soil surface, because of its capability for wide range of frequency and surface roughness. In addition, the first order approximate solution is used for the T_{eff}, that accounts for reflections at layer-interfaces and the attenuation of the radiance through each soil layer [8]. The thickness of soil layers in the top 2.5cm was set at 1mm to capture the strong dynamics of the moisture. Soil below 2.5cm was divided into 1cm layers up to 60.5cm, and modeled as a semi-infinite layer below 60.5cm. SM observations at the depths of 5, 10, 15, 30, and 60cm from MicroWEX-12 represented the values for the modeled layers at 4.5-5.5, 9.5-10.5, 14.5-15.5, 29.5-30.5, and below 59.5cm, respectively. SM values in the other layers were obtained by linearly interpolating values between layers. Soil temperature observed at 5cm was used as the temperature for the modeled layers from 0-5cm. Temperatures for deeper layers, those > 5cm, were assigned in a similar manner to the SM values.

3.3. Microwave Signature of Vegetation

The zero-order approximation of radiative transfer equation, i.e. τ-ω model, is applied to estimate the T_B contribution of the vegetation during the crop season. Typically, ω is considered to be low, typically below 0.06, or neglected at L-band for agricultural vegetation [9]. Thus, the τ becomes the most important factor to characterize impacts of vegetation in the emission model. In this study, two vegetation opacity models, physically-based and empirically-based [4], [10], are evaluated by comparing the estimations of T_B.

The physical-based, cloud density model that considers the vegetation as a dielectric cloudy medium is used, given in [11].

$$\tau = -\int_0^h 2k_0 \,\mathrm{Im}\left[n_t(z)\right]dz \quad \text{(2a)}$$

Where, h is the canopy height, k_0 is vacuum wavenumber ($2\pi/\lambda$), and $n_t(z)$ is the complex refractive index which is estimated [11]

$$n_t(z) = 1 + v_{wc} n_{wc}; \; v_{wc} = \frac{\rho(z)}{\rho_s} \quad \text{(2b)}$$

Where v_{wc} is the volume fraction of the wet vegetation, n_{wc} is the refractive index of the wet vegetation, ρ_s is the density of wet vegetation depending on vegetation type, and $\rho(z)$ is the density of wet vegetation and air, also called cloud density. The cloud density of the vegetation can be estimated from the fresh biomass with respect to canopy height [10].

The cloud density model is evaluated by comparing the empirical model, $\tau = bW$, on the estimations of T_B from forward models to microwave radiometric observations at L-band during the crowing vegetation. The impacts due to the incidence angle and polarization on the τ values are also explored in this study [12].

4. PRELIMINARY RESULTS

In corn, the observed and estimated T_B at H-pol using the physically-based, cloudy density model, is compared with its Root Mean Square Difference (RMSD) of 16 K during the mid-season (DoY 173-212) when VWC was between 1-6 kg/m^2, and RMSD of 9 K in the late-season

(DoY after 212) when VWC was between 6-9 kg/m^2. The higher RMSD in the mid-season is due to the soil dominant contribution to T_B that is significantly overestimated during precipitations [13].

For the soybean, the RMSD of observed and estimated T_B at H-pol are 19 K and 31 K, during the mid-season (DoY 180-212) when the VWC was between 1-3 kg/m^2 and the late-season (DoY after 212) when the VWC was 3-4 kg/m^2, respectively. The physically-based, cloud density model for τ significantly underestimates the contribution of soybean in the late season. The empirically-based model with higher b value [12] for soybean than corn compensates such an underestimation. We will discuss such an effect and apply the modified vegetation algorithm in analysis of the scale variability of T_B.

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