VEGETATION OPTICAL DEPTH AND SOIL MOISTURE RETRIEVAL USING L-BAND RADIOMETRY OVER THE ENTIRE GROWING SEASON OF A WINTER WHEAT STAND

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ABSTRACT

This paper describes the first results of a field experiment conducted at the Selhausen remote sensing field laboratory (Germany) over the entire growing season of a winter wheat. Brightness temperature measurements were performed with the passive microwave L-band radiometer ELBARA-II. The data were collected above two different footprints within a homogeneous winter wheat stand in order to disentangle between the radiation originating from the soil and the radiation originating from the vegetation. In a first step, the brightness temperature (T_B) data collected above the first plot with the soil surface covered by a metal grid (i.e., blocking the radiations from the ground) were used to retrieve the vegetation optical depth (τ). In a second step, T_B data collected above the second plot without the metal grid on the soil surface were used to retrieve the soil surface moisture using several inverse modeling approaches. All modeling investigations were performed with the simple zero-order τ-ω model. The results show that using τ data derived from the first plot as a priori information, which showed to be time, polarization, and angle dependent, allows us to improve the soil moisture retrieval, due to a better representation of the vegetation canopy effect on the measured T_B. Furthermore, the correlations between τ and different vegetation indices were analyzed and highlight the potential of τ in terms of vegetation monitoring for, e.g., all-weather measurements compared to optical measurements.

Index Terms— L-band radiometry, soil moisture, vegetation optical depth, field experiment, SMOS, SMAP

1. INTRODUCTION

Soil surface moisture is a key variable in the global water cycle and is also of great interest for several research fields like agronomy, climatology, hydrology, and geomorphology. The L-band (1 - 2 GHz) microwave radiometry is a promising technique in comparison to higher microwave frequencies techniques to estimate the soil moisture and also vegetation properties as it has several benefits. The soil and vegetation emission depth is larger, the vegetation layer can be assumed semi-transparent, and also the scattering inside the vegetation layer is low as well as the soil surface roughness effect is reduced. In addition, most passive L-band radiometer systems operate at 1.4 GHz (λ ~ 21 cm), which is a protected frequency band where radio frequency interferences (RFI) are limited [1,2]. Nevertheless, the vegetation layer still attenuates the emission originating from the soil, which has to be accounted for in the soil moisture retrieval algorithms [3]. To overcome this limitation, tower-based radiometer measurements are still needed to improve and validate the radiative transfer models.

The first objective of this study is to characterize the time, polarization, and angle dependency of the vegetation optical depth (τ) retrieved from L-band radiometry. A second objective is to investigate the impact of the quality of the τ information on the soil moisture retrieval. Current space borne soil moisture retrieval approaches will be also assessed, such as the use of a polarization and angle independent τ in the SMOS and SMAP retrieval algorithms [4]. Finally, the correlations between the radiometer-derived τ values and in situ measured vegetation properties will be presented to investigate the potential of using τ for vegetation properties monitoring.

For that, a controlled tower-based experiment using the ELBARA-II radiometer was performed during the summer 2017 over the entire growing season of a winter wheat over two different footprint types. Soil moisture and τ were both retrieved by inverting L-band brightness temperature data using the τ-ω radiative transfer model [5].

2. L-BAND RADIOMETER SYSTEM

Brightness temperature data were acquired using the L-band radiometer ELBARA-II. The measurements were performed at horizontal (p = H) and vertical (p = V) polarization (p) using a 3-s integration time to provide an accuracy of about 1 K. The radiometer was attached to a dual-mode conical horn antenna (60 cm in diameter and 67 cm long) with symmetrical and identical beams and a -3 dB full beam width of 23° in the far field. The whole system was fixed at about 4 m height on a moving platform (see Figure 1).

3. FIELD EXPERIMENT AND SETUP

This study was conducted at the Selhausen remote sensing field laboratory (Germany) [6]. A picture of the setup can be seen in Figure 1. The field experiment was performed over a winter wheat stand during a complete growing season between the 10th of April (DOY 100) and 14th of August 2017 (DOY 226). Measurements of passive L-band microwave radiations over two plots were performed to disentangle radiative contributions originating from the soil and vegetation [6]. The first plot consists of a reflector (mesh grid) covering the soil with wheat plants growing through, while the second plot was not covered by a reflector on the soil. The reflector is a wire grid with a mesh-size < 1 cm to achieve a highly reflecting surface, neither disturbing hydrology, nor plant growth. Using this experimental approach it is possible to measure the brightness temperature (T_B) of the vegetation layer only (first plot), while the soil surface layer emission is completely blocked by the grid.

The radiometer measurements were performed for different viewing angles between 40° and 60° in increments of 5° and were repeated twice a week above the gridded and non-gridded plots. Each measurement was performed during 20 min using a 5 min interval (equal to 5 data per angle). Additionally, in situ sensors were installed to monitor the soil surface moisture (5 cm depth), soil temperature, vegetation temperature, and vegetation structure (using optical cameras) at both plot sites. On the other hand vegetation characteristics were measured destructively in the laboratory once a week, namely, the vegetation water content (VWC), leaf area index (LAI), total of vegetation biomass (TOB), and vegetation height.

Figure 1: Ground-based microwave remote sensing laboratory in Selhausen, Germany.

4. MODELING

In the L-band frequency range, the emission of a vegetation layer covering a soil layer can be described by a simple radiative transfer (RT) model called the τ-ω model, which is a zero-order solution [5]. This model is used to retrieve τ from the T_B data collected above the gridded plot as well as to retrieve the soil dielectric permittivity (ε_S) from the T_B data measured above the non-gridded plot. Different retrieval schemes were used to retrieve the ε_S, namely the 1-parameter approach, where only ε_S is retrieved using the τ values retrieved from the gridded plot T_B data as a priori information (comparable to the current SMAP approach), and the 3-parameter approach where ε_S, τ_H, and τ_V are retrieved simultaneously without ancillary information on τ (comparable to the current SMOS approach, but with a polarization dependent τ). The 1-parameter approach was performed for each measurement angle separately (single-angle approach) and for the different angles at the same time (multi-angle approach), while the 3-parameter approach was only performed for the multi-angle dataset. The single scattering albedo (ω) and the effective surface roughness parameter (H_R) were both set equal to zero during the soil moisture retrievals.

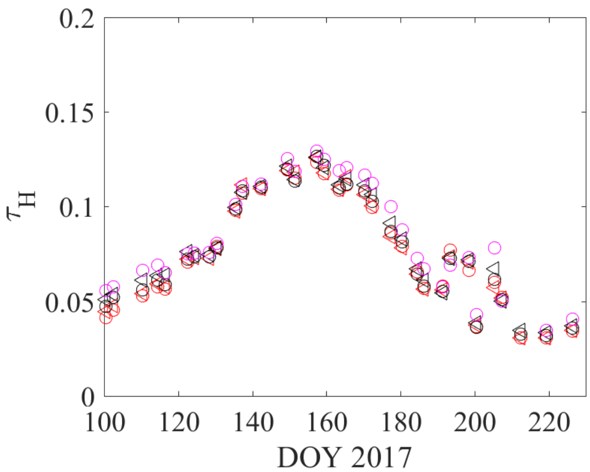
5. RESULTS

This section presents the results of the τ retrieval, followed by a comparison between the measured and modeled ε_S for the two retrieval approaches. Finally, the correlation between τ and the vegetation properties (i.e., VWC and LAI) is investigated.

5.1. Vegetation optical depth

The results of the τ retrieval from the gridded plot T_B data are depicted in Figure 2 for both H-polarization (a) and V-polarization (b). Only the single-angle approach results are presented in this part, as the multi-angle approach results show very similar values. Concerning the temporal variation, the lowest τ values can be observed at the beginning of the growing season (tillering stages) and at the end (senescence stages), while the highest values can be observed around DOY 150 till 160 (end of flowering). In general, it can be stated that the emission attenuation by the vegetation layer is less pronounced at H- polarization as at V-polarization, and the dataset shows a clear angular dependency of τ at V-polarization. The mean of τ_H is about 0.08 for all angles with a standard deviation of about 0.03. The mean values of τ_V increase with increasing angle with values of about 0.17 (40°), 0.20 (45°), 0.22 (50°), 0.23 (55°), and 0.24 (60°). The highest angular dependency is detectable for a fully developed vegetation cover (DOY 160), and is negligible when the vegetation is fully senescent (after DOY 200). This can be mainly related to the increase and decrease of the VWC and LAI. The ratio between τ_H and τ_V (ratio = τ_V/ τ_H) varies between 2 and 4 with highest values when the vegetation layer is fully developed between DOY 140 and 180.

(**a**)



(**b**)

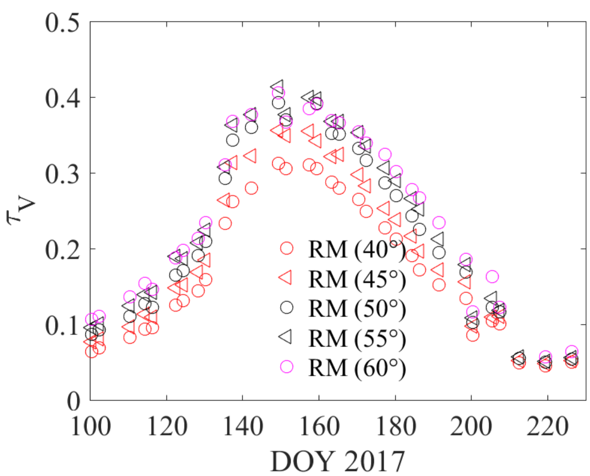


Figure 2: Estimated τ values over time at both polarizations for the different viewing angles.

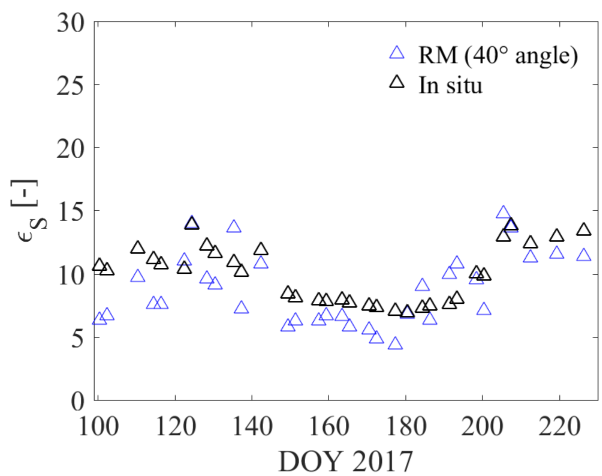
5.2. Soil dielectric permittivity

Soil dielectric permittivity (ε_S) values were retrieved from the non-gridded plot T_B data using a 1-parameter approach (Figure 3 a-b) and a 3-parameter approach (Figure 3 c).

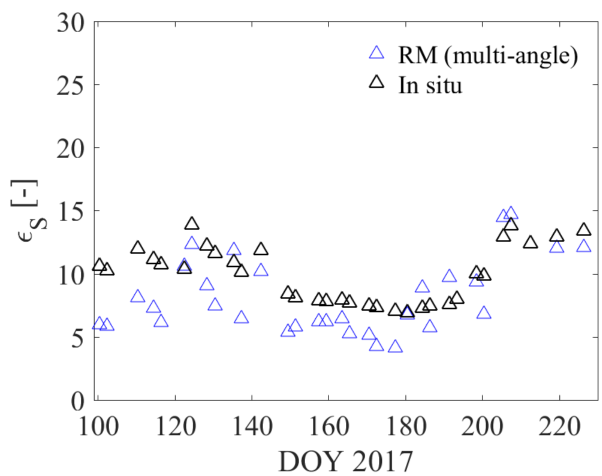
For the 1-parameter approach, the retrieved ε_S values are in a good agreement with the in situ measured data set with a R^2 of 0.57 and 0.58 for the single-angle approach and the multi-angle approach, respectively, as well as an unbiased RMSE of 1.85 and 1.89 and a bias of -1.22 and -1.85 for the single-angle approach and the multi-angle approach, respectively.

The results of the 3-parameter approach show comparable good estimates of ε_S as the 1-parameter approach in terms of R^2 with a value of 0.65. The value of 3.42 for the unbiased RMSE and the value of 2.76 for the bias indicate a less pronounced agreement between the measured and modeled ε_S. Furthermore, also the τ values were retrieved simultaneously during the 3-parameter approach. In comparison to the τ values presented in section 5.1 this approach fails to retrieve the time variations of τ, showing values relatively constant over the entire growing season starting at 0.2 and decreasing to values around 0.1 during the senescence stages.

(**a**)



(**b**)



(c)

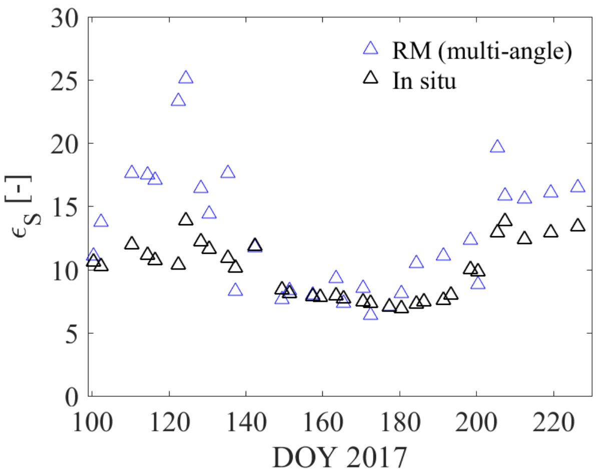


Figure 3: Soil dielectric permittivity (ε_S) retrieved from the T_B data collected above non-gridded plot using the 1-parameter approach (a and b) and the 3-parameter approach (c).

5.3. Correlations between vegetation optical depth and in situ measured vegetation parameters

In this section, the τ values retrieved from the gridded plot T_B data at 40° angle are compared to the in situ VWC and LAI measurements using a simple linear regression. Both VWC and LAI are strongly correlated to the retrieved τ. The correlations between τ_V and VWC and between τ_V and LAI are relatively similar, with a R^2 of 0.88 and 0.87, respectively. The correlation between τ_H and VWC is slightly lower with a R^2 of 0.79, and higher between τ_H and LAI with a R^2 of 0.89.

6. FIRST CONCLUSIONS

This study shows that over a wheat canopy τ has a strong polarization dependence as the vegetation attenuation at V-polarization is stronger. The results also show that τ has an angular dependency at V-polarization. Finally, τ shows a clear seasonal trend (time dependency) which corresponds to changing vegetation properties (mainly VWC and LAI).
The use of a time, polarization, and angle dependent τ as a priori information on the soil moisture retrieval reveals a significant improvement in the modeled ε_S (1-parameter approach) in comparison to the approach where τ and ε_S were retrieved simultaneously (3-parameter approach). Based on these results, there is a need to further discuss the assumptions on the τ parameter made by the SMOS and SMAP algorithms for soil moisture retrieval.
Finally, the correlations between the vegetation parameters (i.e., VWC and LAI) and τ show a strong relationship for both polarizations over the entire growing season of the winter wheat. There is thus a high potential of using τ information for vegetation properties monitoring.

7. REFERENCES

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