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

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ABSTRACT

This paper describes the first results of a field experiment conducted at the TERENO test site in Selhausen (Germany) over the entire growing season of a winter wheat canopy. The measurements were performed with the passive microwave L-band radiometer ELBARA-II. The data were collected above two footprint types (natural and manipulated), in order to disentangle between the radiation originating from the soil and the radiation originating from the vegetation. Using the brightness temperature (T_B) measurements of the manipulated plot (i.e., only vegetation emission) the simple zero-order τ-ω model was used to retrieve a time-, polarization-, and angle- dependent vegetation optical depth value at nadir angle (τ_{NAD}). The results show that a time-, polarization-, and angle dependent τ_{NAD} is able to improve the soil moisture and vegetation properties retrieval. Furthermore, the correlation between τ_{NAD} and different vegetation indices is analyzed and highlights the potential of τ_{NAD} in terms of vegetation monitoring.

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 and the vegetation canopy, which has to be accounted for in the soil moisture retrieval algorithms [3]. On the other hand, it is still a major challenge to disentangle between the emissions originating from the soil and vegetation.

The objective of this study is to improve our understanding about the attenuation of the vegetation layer on the L-band emissions and to improve the soil moisture retrieval from L-band brightness temperature data. For this purpose, a tower based experiment using the ELBARA-II radiometer was performed during the summer 2017 over the whole growing season of a winter wheat. Soil moisture and vegetation optical depth were both retrieved by inverting L-band brightness temperature data using a radiative transfer model [4]. This paper investigates the impact of accounting for a polarization- and angle- dependent vegetation optical depth (τ_{NAD}) parameter in order to improve the current spaceborne soil moisture products [5].

Finally, the correlation between the radiometer-derived τ_{NAD} values and in situ measured vegetation parameters will be presented to investigate the potential of using τ_{NAD} for monitoring vegetation characteristics.

2. L-BAND RADIOMETER SYSTEM

Brightness temperature data were acquired using the dual-pol 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.

3. FIELD EXPERIMENT AND SETUP

A schematic view of the field experiment and setup is depicted in Figure 1. This study was conducted at the TERENO (Terrestrial Environmental Observations) test site in Selhausen, Germany [6]. The investigated target is a vegetation canopy covering the soil composed of winter wheat 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 footprint types (natural and manipulated) were performed to disentangle radiative contributions originating from the soil and vegetation [6]. The manipulated footprints consist of a reflector covering the soil with wheat plants growing through, while the natural footprints consist of a soil covered by winter wheat plants only. 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, while the soil surface layer emission is reflected by the grid.

The radiometer measurements were performed manually for different viewing angles between 40° and 60° in increments of 5° and were repeated twice a week above the natural and manipulated plot measuring the T_B for each angle for 20 min using a 5 min interval (equal to 5 measurements per angle). Additionally in situ sensors were installed to monitor the soil surface moisture (5 cm depth), soil temperature, vegetation temperature, and the vegetation structure (using optical cameras) at both plot sites. On the other hand vegetation characteristics were measured destructively, namely, the vegetation water content (VWC), leaf area index (LAI), total of vegetation biomass (TOB), and vegetation height. The purpose of those measurements is to provide ground truth data as a reference for the soil moisture and vegetation properties retrieved from the radiometer measurements.

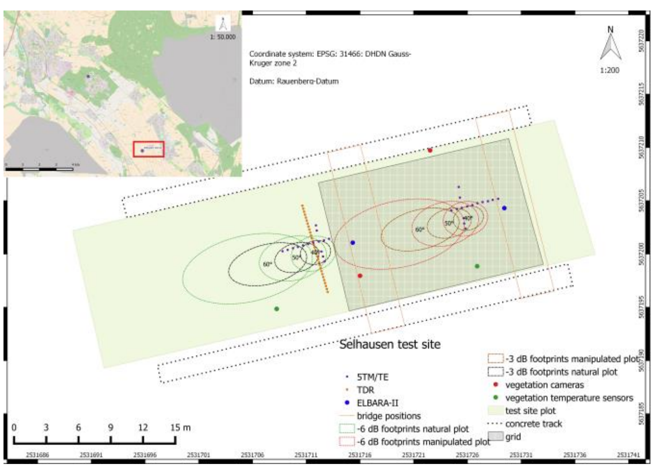

Figure 1: Schematic view of the field experiment setup.

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 [4]. A sketch of the model is shown in Figure 2. This model is used in a two-step approach to retrieve first the τ_{NAD} from the manipulated plot T_B data and second to retrieve the soil dielectric permittivity (ε_S) from the natural plot T_B data using different inversion schemes. The results of the inversion schemes presented here are namely the 1-parameter inversion, where only ε_S is retrieved using the polarization- and angle dependent τ_{NAD} as an input parameter which is retrieved from the manipulated plot T_B data, and the 3-parameter inversion where ε_S, τ_{NADH}, and τ_{NADV} are retrieved simultaneously without information from the manipulated plot. Both inversions are performed for each measurement angle separately (single-angle approach) and for different angles at the same time (multi-angle approach).

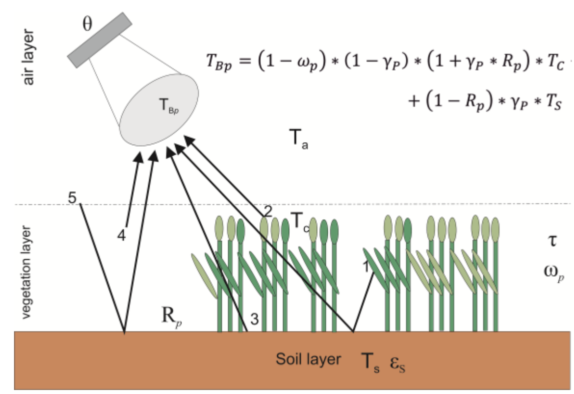

Figure 2: Tau-Omega model.

5. RESULTS

This section presents the results of the estimation of the vegetation optical depth from T_B data, followed by a comparison between the in situ measured and modeled soil dielectric permittivity for the two different inversion schemes. Finally, the correlation between τ_{NAD} and the destructive measurements of VWC and LAI is shown.

5.1. Vegetation optical depth

The results of the inversion of τ_{NAD} show a pronounced temporal evolution over the growing season and also lower values at H-polarization (a) compared to V-polarization (b) (Figure 3). Only the single-angle approach results are presented as the multi-angle approach results represent about the mean value of all angles. The lowest τ_{NAD} 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). The mean of τ_{NADH} is about 0.09 for all angles with a standard deviation of about 0.03. The mean values of τ_{NADV} on the other hand increase with an increasing angle with values of about 0.2 (40°), 0.23 (45°), 0.26 (50°), 0.28 (55°), and 0.31 (60°) and also the standard deviation is much higher than for τ_{NADH} with values of about 0.11 (40°), 0.14 (45°), 0.15 (50°), 0.15 (55°) and 0.15 (60°). 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 data set shows an angular dependency of τ_{NAD} in the V-polarization. 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/LAI.

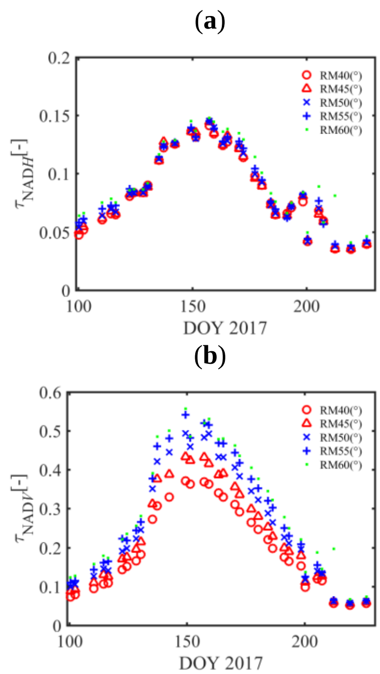

Figure 3: Time-, polarization-, and angle dependent τ_{NAD} for the single-angle approach.

5.2. Soil dielectric permittivity

Soil dielectric permittivity (ε_S) values were inverted from the natural plot T_B data using a 1-parameter inversion (a, b of Figure 4) and a 3-parameter inversion (c, d of Figure 4) approach.

For the 1-parameter inversion approach, the retrieved ε_S values are in a good agreement with the in situ measured data set with a RMSE and bias of about 2.12 and -0.42 for the single-angle approach, and 2.35 and -0.67 for multi-angle approach. Also the R^2 values of about 0.56 and 0.57 indicate a good agreement between the data sets.

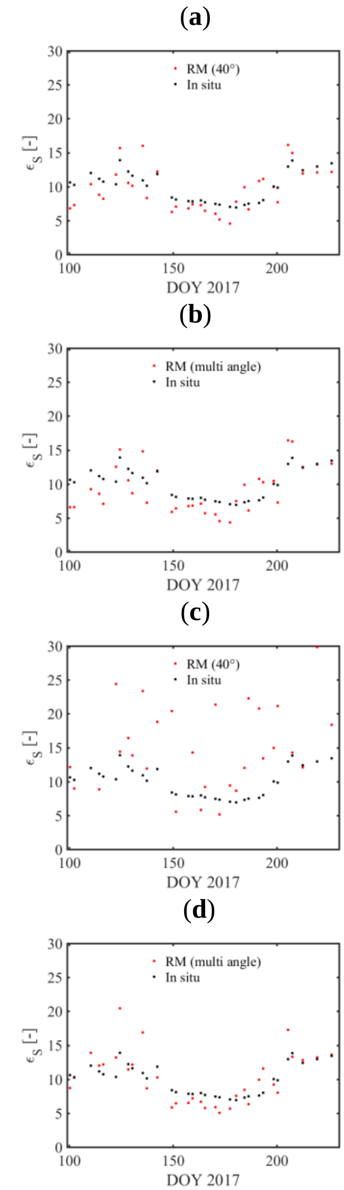

Figure 4: Soil dielectric permittivity (ε_S) retrieved from natural plot T_B data.

The results of the 3-parameter inversion approach on the other hand depict that inversion fails to retrieve ε_S from single angle T_B data with a weak correlation between the measured and modelled ε_S values (R^2= 0.12). The RMSE of 14.66 and the bias of 8.03 confirm the observation. This is due to the fact that one angle T_B data does not contain enough information to retrieve three parameters at the same time. On the opposite, the ε_S values retrieved based on the multi-angle approach shows comparable good estimates of ε_S as the 1-parameter inversion approach with a RMSE of 2.29, a bias of -0.25, and a R^2 of 0.69. Finally, also τ_{NAD} values were retrieved simultaneously during the 3-parameter inversion approach. In comparison to the τ_{NAD}

values presented in section 5.1 this inversion fails to retrieve a time-, polarization-, and angle dependent τ_{NAD} and these values are not useful for vegetation monitoring.

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

The τ_{NAD} values retrieved from the manipulated plot T_B data are compared to in situ VWC and LAI measurements (Figure 5). It can be seen that both VWC and LAI are strongly correlated to the retrieved τ_{NAD} with high values of R^2.

(**a**)

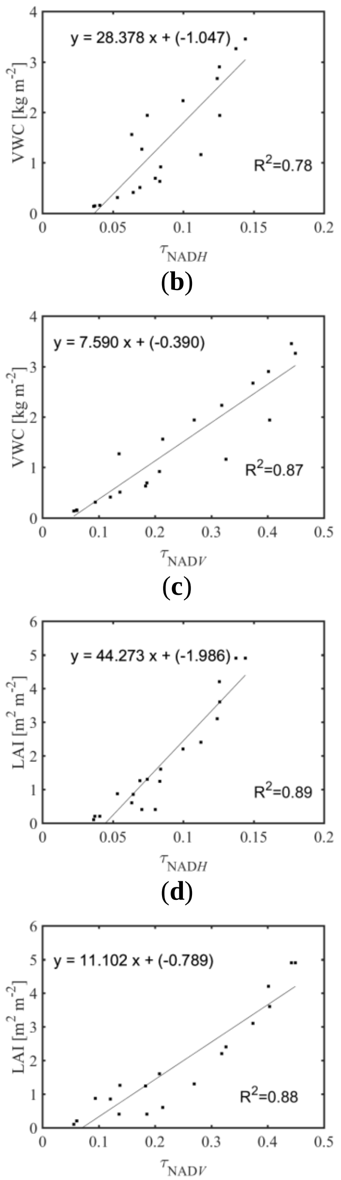

Figure 5: Linear regression between VWC (a and b) or LAI (c and d) and τ_{NAD} at H- (a and c) or V-polarization (b and d).

Concerning the correlation of τ_{NADV} with VWC or LAI the R^2 are quite similar and close to 0.9. The correlation of τ_{NADH} shows to be lower for the VWC with a R^2 close to 0.8.

6. FIRST CONCLUSIONS

This study shows that over a wheat canopy τ_{NAD} has a strong angular dependency at V-polarization. Furthermore, τ_{NAD} should be differentiated between H- and V-polarization (i.e., polarization dependence), as the vegetation attenuation at V-polarization is stronger. In addition the τ_{NAD} shows a high time-dependency which corresponds to changes of the vegetation properties. These assumptions for τ_{NAD} lead to an improvement in soil moisture retrieval in comparison to the current SMOS and SMAP retrieval algorithms. Concerning the correlation between the vegetation parameters (i.e., VWC and LAI) and τ_{NAD}, a strong relationship for both polarizations over the whole growing cycle of the vegetation can be observed.

7. REFERENCES

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