ANALYSIS OF SOIL MOISTURE RETRIEVALS FROM L-BAND PASSIVE RADIOMETRY FOR SOILS WITH DIFFERENT ORGANIC MATTER CONTENT

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INTRODUCTION

Remote sensing methods are still under development in order to improve the spatio-temporal distribution of soil moisture (SM). In this context, the microwave bands are the most suitable to study land-water resources. The Soil Moisture and Ocean Salinity (SMOS), satellite mission of the European Space Agency (ESA), is dedicated to studies of the water in soil over land and salinity of oceans. The part of calibration/validation activities of this satellite, conducted in order to improve soil moisture retrieval algorithms over land, is done with ground-based passive radiometers. ELBARA III (European Space Agency L-band Microwave Radiometer) is located near the Bubnów wetland in Poland. It is capable of mapping microwave emissivity in a local scale [1]. Currently, the SM retrieval algorithms are calibrated for mineral soils despite a small amount of organic matter can significantly change its hydraulic and dielectric properties. Dielectric mixing model for SM retrieval in SMOS considers only clay content, as a fraction that modifies water holding capacity in mineral soil compromising global availability of data. Since organic matter (OM) in soil can increase saturated soil moisture above 0.6 m^3 m^{-3}, which is a boundary of the sensitivity region of SM retrieval algorithms for passive microwave satellites, such studies are of significant importance for further development of soil moisture remote sensing methods.

In this paper we present results of the spatio-temporal mapping of the brightness temperatures on the heterogeneous area of the Bubnów test-site consisting of an area with variable organic matter content and different type of vegetation.

METHODS

The test site (Fig. 1) of approximately 1 ha was located in Eastern Poland, Urszulin commune, near Sęków village, on the border of the Bubnów Wetland (N51.355315, E23.268475). Over 100 soil samples taken were examined in a laboratory to determine the contents of sand, silt, clay, and organic matter.

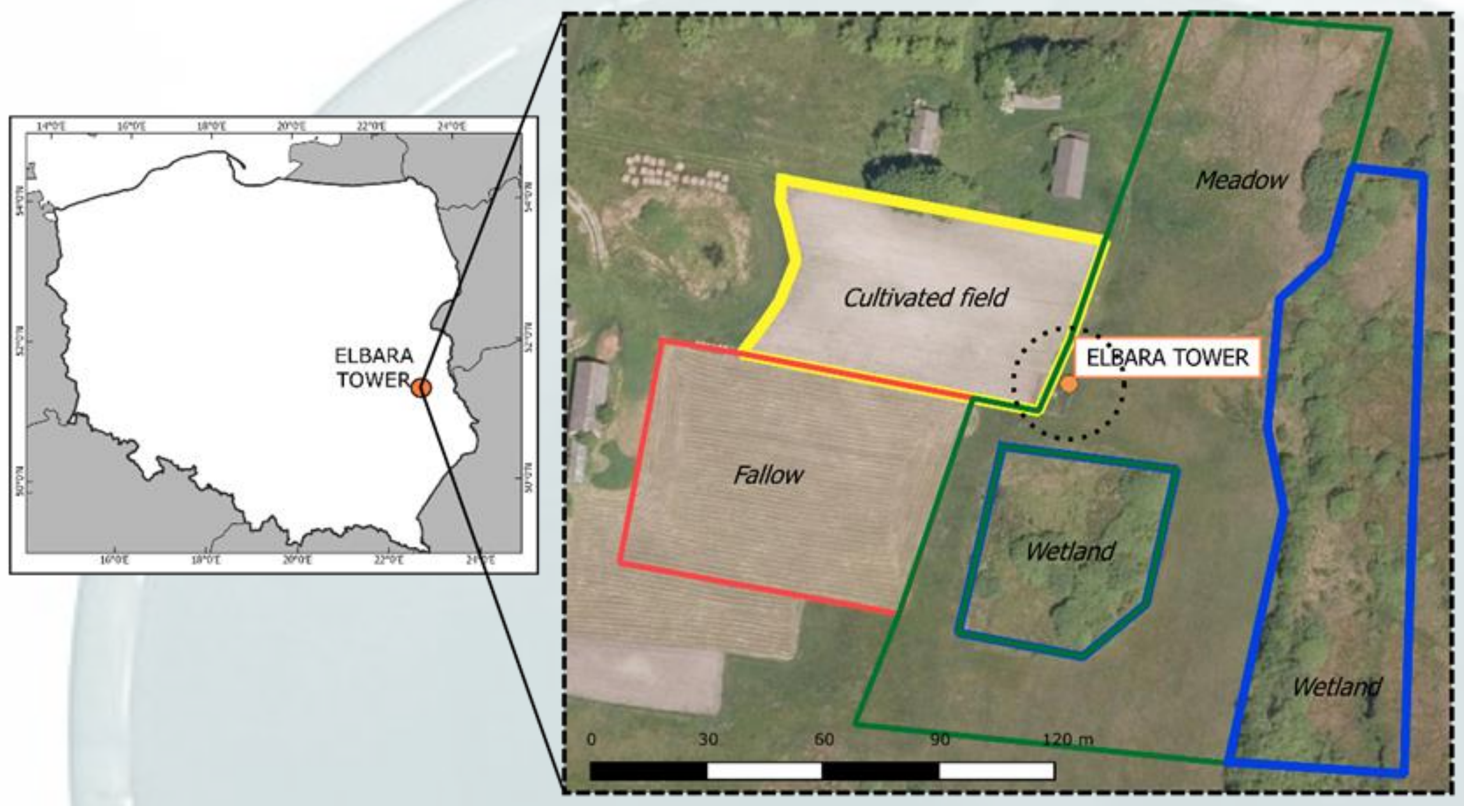

Fig 1. Location of the Bubnów test-site. ELBARA III radiometer is marked with a circle. Dotted circle indicate a range of the radiometric footprint for elevation angle 66°.

SM is retrieved using L-MEB (L-band Microwave Emission of the Biosphere) with applied Simplified Roughness Parametrization [2] for coupling parameters responsible for roughness and vegetation effect on emission. In this approach brightness temperature (T_B) is expressed by the equation:

$$T_{B,p,\theta} = \left(1 - r^*_{G,p,\theta}\exp\left(-\frac{2TR}{\cos\theta}\right)\right) T_{GC}, \qquad (1)$$

where r* is reflection coefficient dependent on dielectric constant of soil (an indirectly dependent of SM), *TR* is a coupled vegetation-roughness parameter, θ is the incidence angle, T_{GC} is ground temperature. For SM modelling, we have used Mironov dielectric mixing model with an input of volumetric water content, clay content and soil temperature [3]. SM retrievals are performed by minimization of the squared difference between measured and estimated brightness temperatures by adjusting chosen free parameters. A parameter that can assess how precipitation influence brightness temperatures and detect water interception by the vegetation is the polarization ratio PR_θ [4]. It can be calculated for a given elevation angle θ (for this study, we have used elevation angle θ = 60°) using the expression as follows:

$$PR_\theta = \frac{T_{B,V,\theta} - T_{B,H,\theta}}{T_{B,V,\theta} + T_{B,H,\theta}}. \qquad (2)$$

RESULTS

1. Spatio-temporal series of brightness temperatures at Bubnów test-site

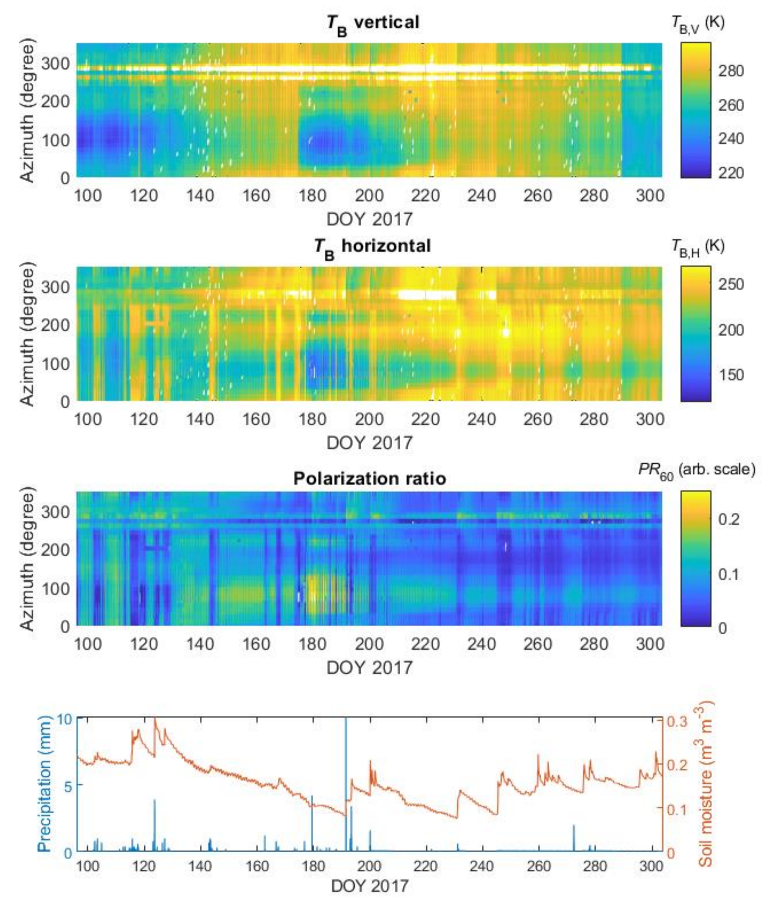

Fig. 2. Hovmöller diagrams of brightness temperatures from ELBARA III and time-series of the SM and precipitation from the agrometeorological station for 2017 (elevation angle 60°). White color is related to brightness temperatures artificially increased by radio frequency interference (RFI) or other factors.

Comparing time-series of T_B and precipitation (Fig. 2), it can be observed that rainfall affects mainly emission polarized horizontally. We observed an increase in the value of $T_{B,H}$, and consequently a decrease PR_{60} during rainfalls. This effect is seen for a majority of azimuths from 0° to 240° and from 310° to 350°. One can see that time-series values along different azimuths are varying suggesting different sensitivity of the radiometer depending on the cover type within a radiometric footprint.

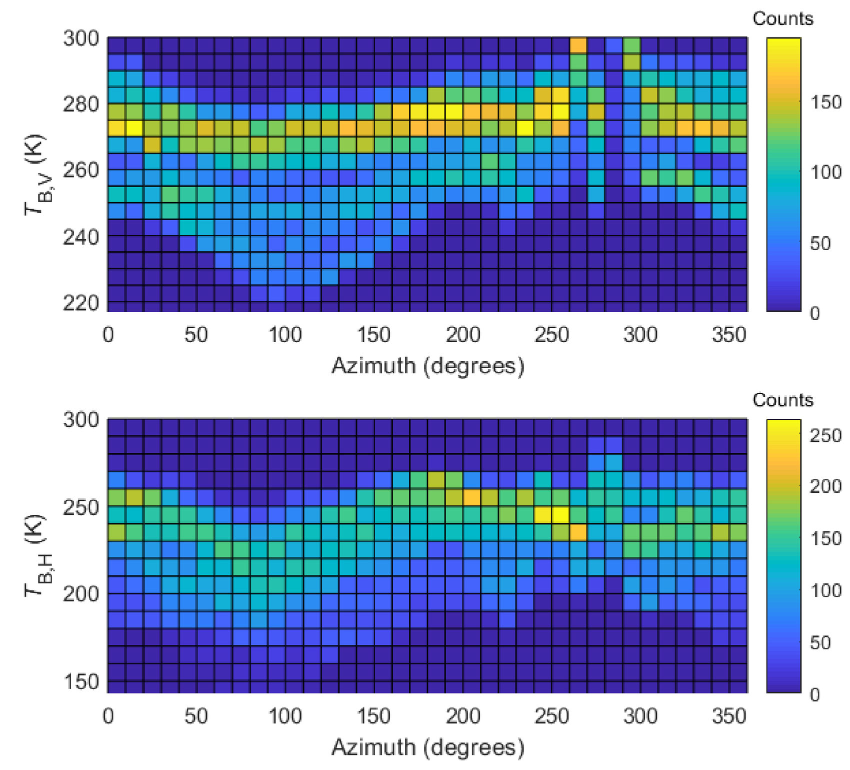

Fig. 3. Bivariate histograms of $T_{B,V}$ and $T_{B,H}$ time-series values vs. the azimuth angle for the analyzed period.

Figure 3 shows that with increasing azimuth from 0° to 80°, one can observe a shift of the histograms to lower brightness temperatures for both polarizations. In this particular azimuth range, we also observed a broadening of the histogram towards lower T_B values that was more noticeable for V than H polarization. For azimuths from 80° to 200° the histogram shifts back to higher temperatures. Next, for azimuths 260° to 290°, we saw disturbances of histograms related to anomalies in $T_{B,P}$, like shifting the peak of the counts distribution to higher temperatures, especially for V polarization. Disturbances in this region can also be seen in the Hovmöller diagrams in Figure 2 and were probably related to RFI from the equipment on agrometeorological station and a lightning protection rod of the ELBARA tower.

2. L-MEB modelling results

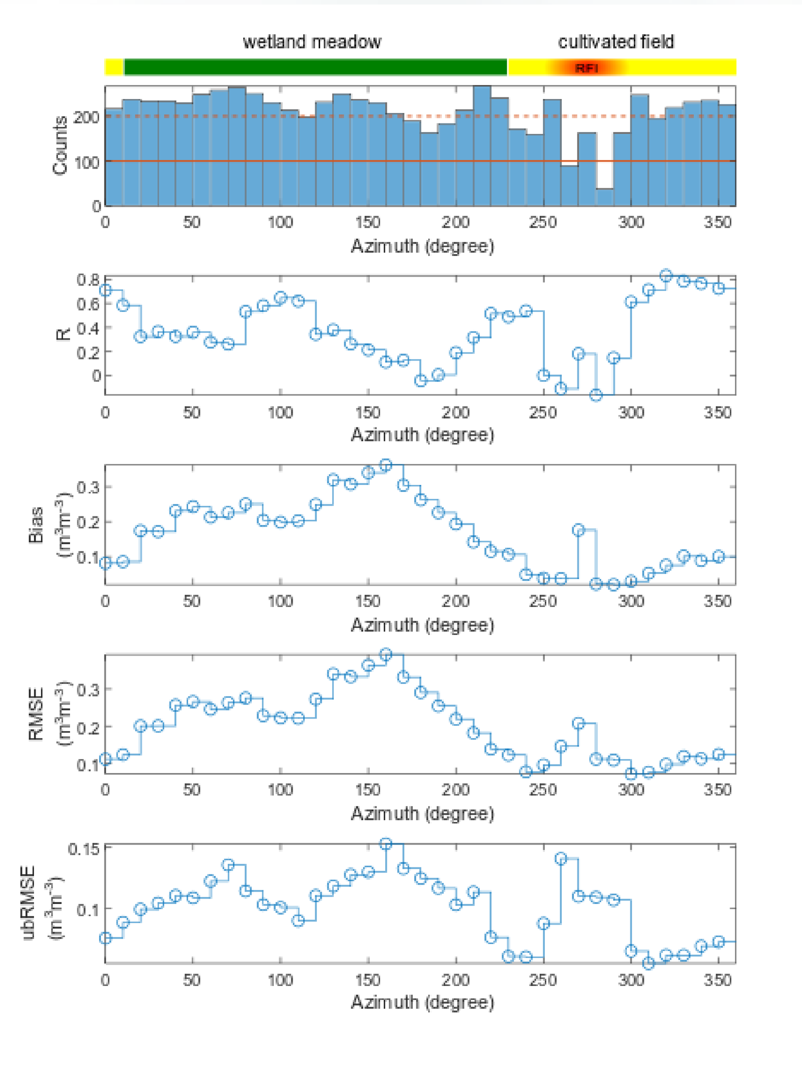

Fig. 4. Spatially resolved statistics results for SM (L-MEB SRP modelling) vs. SM probe data. Summary histogram of data counts after data filtering for every azimuth (top) and statistics by means of Pearson correlation coefficient, bias, RMSE and ubRMSE. Cover type is indicated by a strip on the top of the figure.

Mean correlation coefficient (R) for all azimuths is 0.38 with a standard deviation (σ_R) of 0.27 (Fig. 4). The highest R values are calculated for angles 310°-350° and 0° that cover the area of a cultivated field. We observe a decrease in R coefficient on wetland meadow area. Mean bias is 0.17 m^3 m^{-3} with σ_{bias} = 0.10 m^3 m^{-3}. Unbiasing of RMSE (ubRMSE) gives its mean value across all azimuths of 0.1 m^3 m^{-3} with σ_{ubRMSE} = 0.03 m^3 m^{-3}. The lower values of bias and ubRMSE revealed retrievals over the cultivated field with a minimum of 0.02 and 0.07 m^3 m^{-3}, respectively. The highest bias and ubRMSE is observed for the meadow area at 160° azimuth angle equal to 0.36 and 0.15 m^3 m^{-3}, respectively.

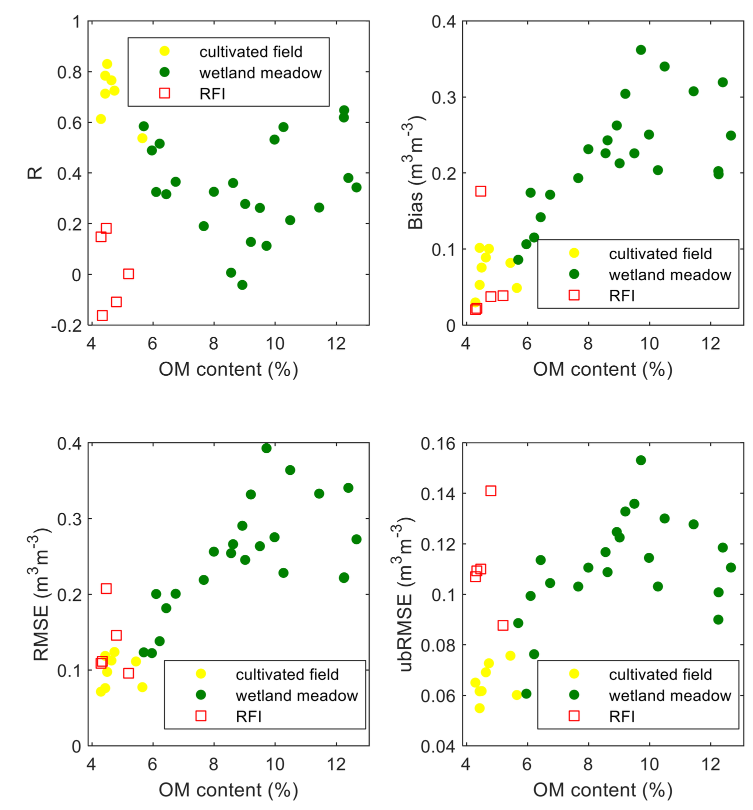

Fig. 5. Statistics, by means of R, Bias, RMSE and ubRMSE, of SM (L-MEB SRP modelling) vs. SM probe data in relation to OM content for three point-groups representing meadow wetland, cultivated field, and RFI regions.

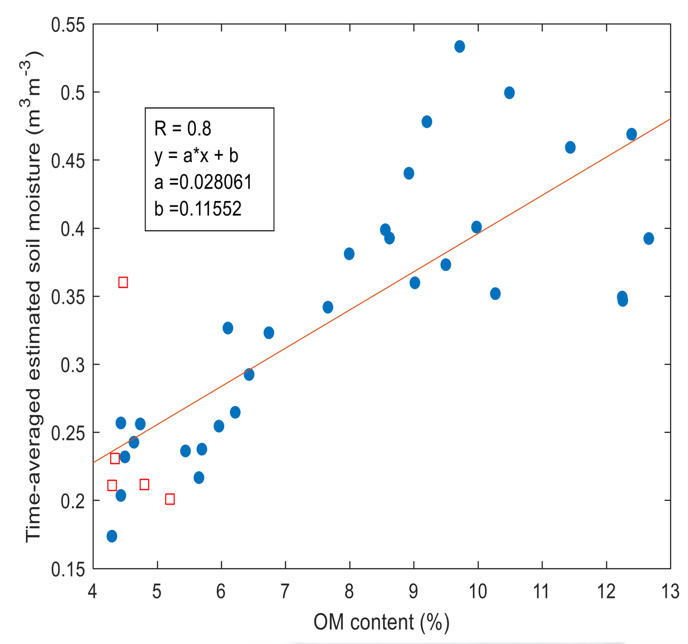

Fig. 6. Time-averaged estimated soil moisture retrieved using L-MEB SRP approach vs. OM content on the adequate azimuths.

The average values of estimated SM time-series for every azimuth confronts the OM content in the investigated footprints (Fig. 6). The correlation coefficient of such a comparison was 0.8 (without taking into account RFI points) indicating a strong relationship between those two quantities.

In the case of R, one could see that the footprints with low OM content (cultivated field) revealed the highest correlation coefficients (Fig. 5). In the low-OM content regions, one could see the values affected by RFI (red squares) gave very low or negative R values. On the areas with OM content above 6%, we observed a wide range of R values from −0.04 (for 9% of OM content) to 0.65 (for 12% of OM content). We observed an increase in bias, RMSE and ubRMSE with increasing OM content. At about 9%, the values of statistical metrics did not show a noticeable trend, but in general, they were considerably higher compared to the low-OM content cultivated field area.

CONCLUSIONS

We have shown that increasing of OM content impacts R (decreasing), bias (increasing), RMSE (increasing), and ubRMSE (increasing) of comparisons. Nevertheless, the modelled time averaged SM values compared to OM content revealed a significant correlation showing that L-MEB SRP can well describe general trends of SM dynamics despite a weak correlation between modelled and measured SM time series.

There is a good agreement between measured and estimated SM values within areas with relatively low OM content (4% - 6% - cultivated field). Further increase in OM content, starting from approximately 6% (wetland meadow), causes an increase in bias, RMSE, and ubRMSE values and a general drop in R. Despite a span of obtained R values, we found that time-averaged estimated SM using L-MEB SRP approach strongly correlates with OM contents.

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ACKNOWLEDGMENTS: The research was partially conducted under the projects "Water in soil—satellite monitoring and improving the retention using biochar" no. BIOSTRATEG3/345940/7/NCBR/2017, which was financed by the Polish National Centre for Research and Development in the framework of "Environment, agriculture and forestry"—BIOSTRATEG strategic R&D programme; the ELBARA_PD (Penetration Depth) project No. 4000107897/13/NL/KML funded by the Government of Poland through an ESA (European Space Agency) contract under the PECS (Plan for European Cooperating States) and ESA contract No.: 4000113360/15/NL/FF/gp.