A simple method for soil moisture calculation using data from ELBARA III passive radiometer and thermal inertia

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Introduction

The soil is a heterogonous substance consists of three phases: solid, gas and liquid, where the latter is mainly water – the natural solvent with very high heat capacity. Due to this physical property and the fact that water is a common substance on our planet, it has a significant impact for stability of the climate on Earth. Another water property, the dielectric constant much higher than in other soil ingredients, is often used to determine soil water content. As an example, the Time Domain Reflectometry (TDR) technique for *in situ* soil moisture (SM) measurements may be mentioned. For SM assessments at global scale, the satellite-based instruments were launched into space, e.g. Soil Moisture and Ocean Salinity (SMOS) or Soil Moisture Active Passive (SMAP). Those satellites are measuring brightness temperature (BT) of soil in microwave (L-band) domain. ELBARA (European Space Agency L-band Radiometer) also measures BT of soil and is used for SM retrieval algorithms development. Those algorithms uses nonlinear optimization and engage several parameters such as soil temperature, its roughness and vegetation cover. In the presented work, we introduced a much simpler method that base on three facts: i) a high water heat capacity cause that, during the diurnal night/day cycle, the soil with higher water content cools down and heats up slower than dry soil. This phenomenon was quantified by thermal inertia; ii) brightness temperature is related to the effective temperature of the surface and iii) plants are generally semi-transparent for L-band microwaves, what gives a possibility for probing soil properties underneath vegetation. The proposed approach seems to be reasonable, as both variables, brightness temperature and thermal inertia, strongly depend on soil water content.

Materials and methods

Thermal inertia is "the degree of slowness with which the temperature of a body approaches that of its surroundings" (Webster). The thermal inertia of the soil is defined as:

$$TI = C_v\sqrt{D} \equiv \sqrt{C_v \lambda}$$

where $\boldsymbol{C_v}$ is heat capacity, $\boldsymbol{D}$ is thermal diffusivity and $\boldsymbol{\lambda}$ is thermal conductivity of soil.
To simplify the remote-sensing-based estimation we used apparent thermal inertia, ***ATI*** *(K^{-1})*, defined as (Price, 1985):

$$ATI = \frac{1-\alpha}{\Delta T}$$

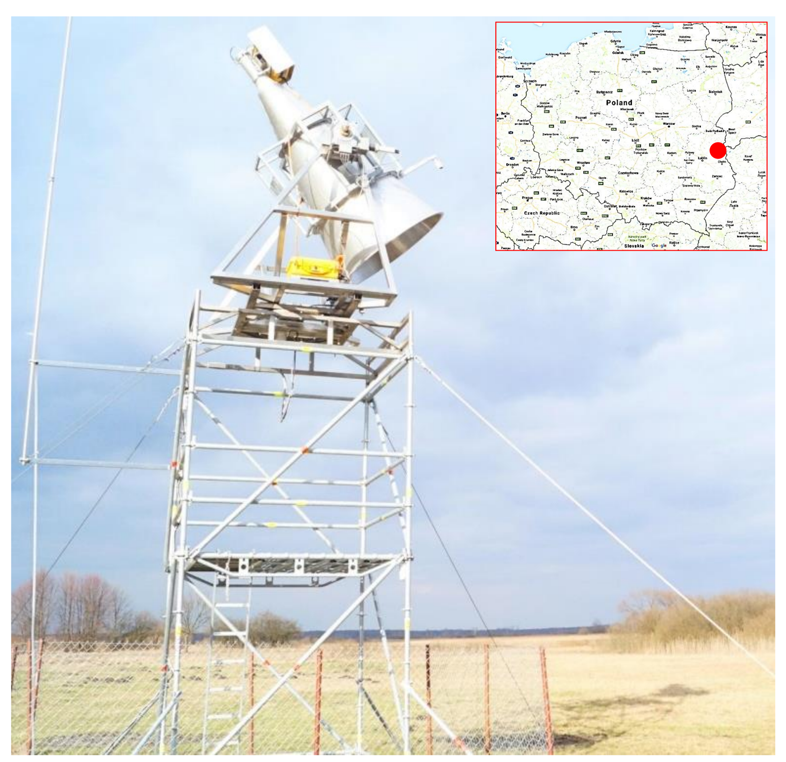
where $\boldsymbol{\alpha}$ is the surface albedo and $\boldsymbol{\Delta T}$ is the maximum soil surface temperature variation, calculated on a daily basis (in our case $\boldsymbol{BT_{noon} - BT_{midnight}}$ measured by ELBARA). We have chosen footprints where the minimum and/or maximum ***ATI*** derived from L-band corresponded to the minimal and maximal observed soil moisture contents ($\boldsymbol{SM_{min}}$, $\boldsymbol{SM_{max}}$ respectively). Soil moisture for each footprint was calculated from modified formulae of Verstraeten et al. 2006:

$$SM(t) = \frac{ATI(t) - ATI_{\min}}{ATI_{\max} - ATI_{\min}} \cdot (SM_{\max} - SM_{\min}) + SM_{\min}$$

where $\boldsymbol{\alpha}$ is the surface albedo. Plants are generally semi-transparent for L-band microwaves and roughness was almost constant, so we assumed that L-band soil albedo (needed in thermal inertia computations) is constant.

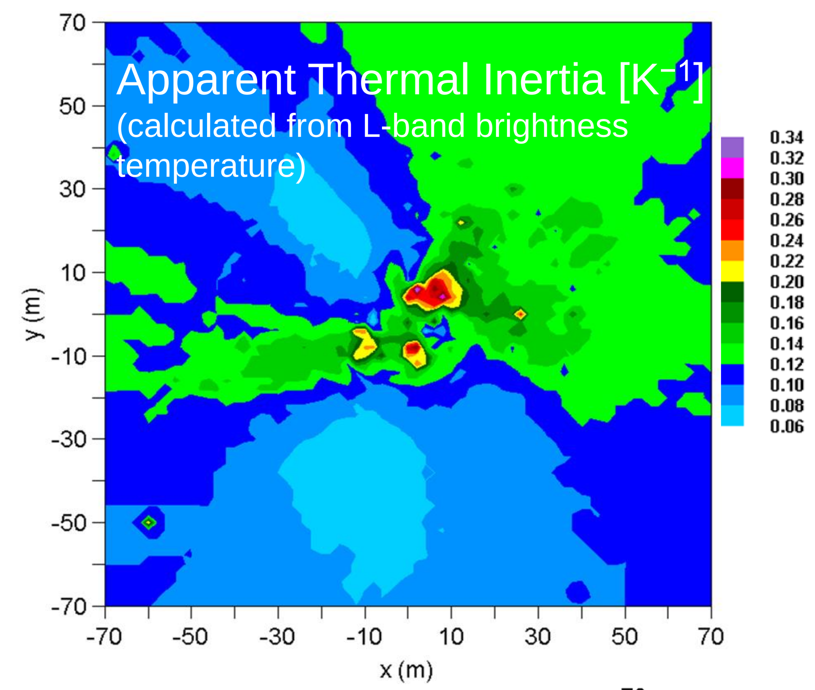
Bubnow test site

Bubnow test site is placed in Poland, at the border of different vegetation and soil types: cultivated field, meadow, fallow and marsh (peat-bog with seasonally standing water). The soil moisture may vary from 0 % for mineral soil up to 95% for peat. Test site is 200×200 m. ELBARA III, the 1.4 GHz ESA passive radiometer, is placed in the centre, on 6 m tower, near agrometeorological stations (that provide soil moisture, weather and other data for reference). Radiometer trackers enables to observe high number of quasi-simultaneous footprints by rotating antenna in horizontal (azimuth range 0-350°) and vertical plane (incidence angle range 30-85°). There are 4 measuring sessions per day: at midnight (00:00 AM), in the morning (6:00 AM), noon (12:00 PM) and in the evening (6 PM) and sky calibration near midnight.

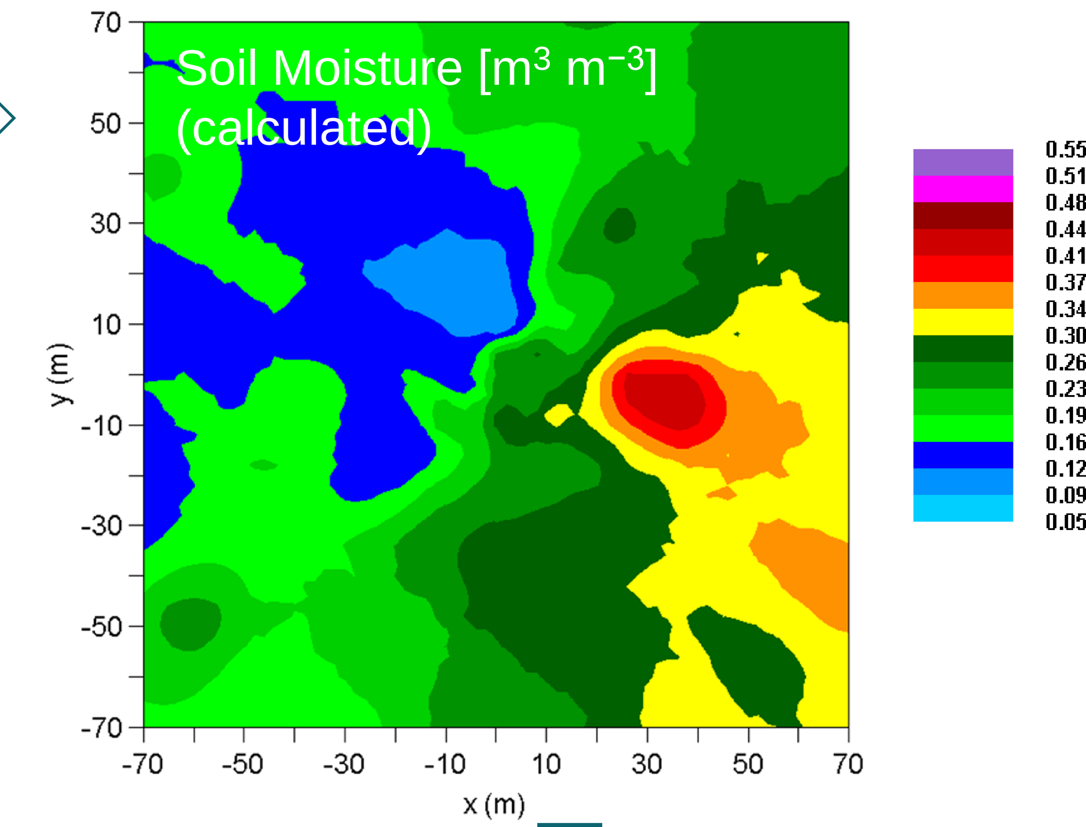


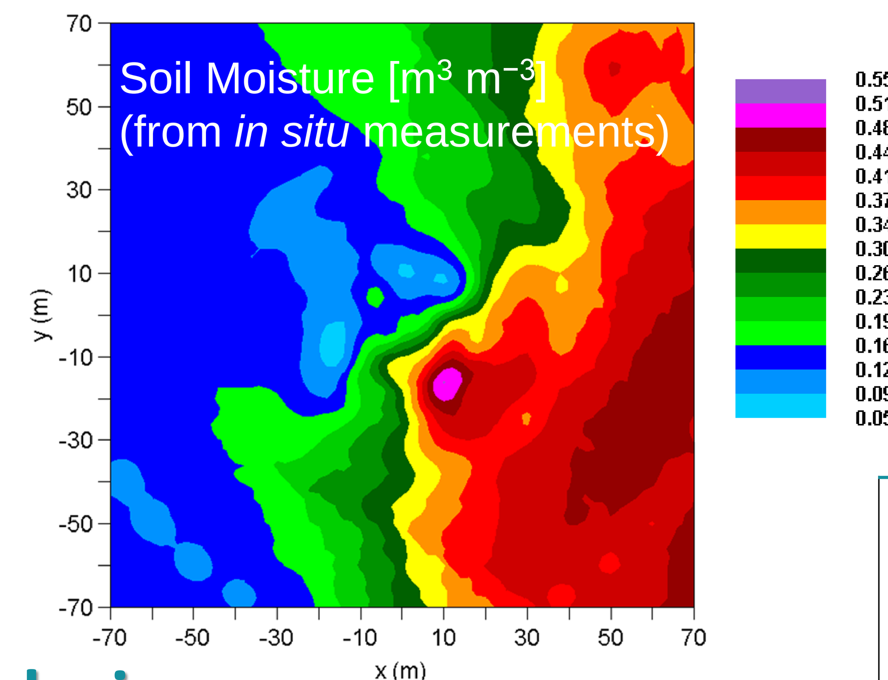
In 2016-2019 we conducted 16 field campaigns. We measured surface soil moisture *in situ* using TDR, and interpolate it to semi-continuous grid using geostatistics. Then, the driest and the wettest points (in space and time) were chosen and assigned to, maximum and minimum thermal inertia, respectively. Basing on that, the model retrieving soil moisture was built, and the other measurements served as evaluation assembly.

Results



thermal inertia approach





comparison

Date of campaign (*in situ* measuremets of SM)	SM *in situ* vs. SM obtained from V ELBARA brightness temperatures	
	Regression equation	R^2
22/03/2016	y = 1.29x - 0.22	0.91
06/05/2016	y = -0.53x + 0.41	0.01
18/05/2016	y = 2.51x - 0.66	0.32
03/06/2016	y = 0.29x + 0.10	0.01
28/07/2016	y = 1.22x + 0.02	0.62
19/09/2016	y = 0.21x + 0.14	0.13
03/11/2016	y = 0.48x + 0.08	0.20
23/05/2018	y = 0.48x + 0.15	0.15
27/06/2018	y = 2.04x - 0.11	0.85
13/09/2018	y = 1.45 + 0.20	0.33
23/07/2019	y = 0.67x + 0.23	0.72
08/10/2019	y = 0.79x + 0.17	0.50
ALL	y = 0.60x + 0.11	0.31

Summary and Conclusions

In the presented work we introduced a simple soil moisture retrieval algorithm that base on the fact that soil with higher water content cools down and heats up slower than dry soil. This phenomenon was quantified by measuring temperatures (in fact brightness temperatures) using L-band radiometer ELBARA and computing simplified apparent thermal inertia. That idea came from general knowledge, that both variables, brightness temperature and thermal inertia strongly depend on soil moisture. The results were compared to *in situ* soil moisture data obtained during field campaigns. It was noticed, that modelled soil moisture is in some relation (varying from weak to strong) with the measured soil moisture. The discrepancies are probably associated with vegetation cover, dew and numerous soil properties not taken into in this study. **The presented research focused on modelling in the small-size test site, however, the proposed method is promising for larger scales as well, due to similarities between ELBARA and SMOS or SMAP.**

References

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