Relating Surface Reflectance and Near-Surface Soil Moisture to Improve Ground Truth Calibration of Optical Remote Sensing

Ebrahim Babaeian[1], Morteza Sadeghi[2], Wenyi Sheng[2], Rong Zhou[2], Scott B. Jones[2], and Markus Tuller[1]

THE UNIVERSITY OF ARIZONA

[1] University of Arizona, Department of Soil, Water and Environmental Science, Tucson, AZ

[2]Utah State University, Department of Plants, Soils and Climate, Logan, UT

UtahStateUniversity

Introduction

- Remote sensing (RS) provides an exceedingly powerful means for large scale quantification and monitoring of surface (skin) and near-surface soil moisture dynamics. However, the relatively small penetration depth of electromagnetic radiation within the optical and microwave frequency domains in conjunction with the limited spatial resolution of off-the-shelf moisture sensors employed for ground truth calibration provide a challenge to accurately measure moisture dynamics close to the soil surface. To better understand the relationship between surface and near-surface soil moisture we employed a benchtop hyperspectral line scan imaging system to generate high resolution surface reflectance and soil moisture maps during evaporation from soil boxes instrumented with a novel time domain reflectometry (TDR) sensor array that allows monitoring of near surface moisture at 5-mm depth resolution. The measurements and the development of new sensor technology are intended to improve ground truth calibration of airborne and satellite RS soil moisture observations.

Materials and Methods

- A Resonon Pika NIR line scan camera with a spectral range from 900 to 1700 nm and a spectral resolution of 5.5 nm was employed to image changes in soil surface reflectance during evaporative drying (Fig. 1).
- The soil was compacted into a 5-cm deep rectangular box equipped with a novel TDR sensor array installed at a 30° tilt to achieve 5-mm measurement resolution. A *Campbell Sci.* TDR200 prototype was used to generate the electromagnetic pulse and a SDMX50 coaxial multiplexer was employed to switch between the 8 individual probes of the sensor array. The system was automated with a *Campbell Sci.* CR6 datalogger (Fig.1).
- To speed up evaporation, a constant stream of about 30°C warm air generated by a 400 watt enclosure heater with CPU fan was guided over the soil surface. The mass change was recorded with a high-resolution load cell (Fig. 1). The initially saturated sample was scanned every 15 minutes until the surface reflectance remained constant.

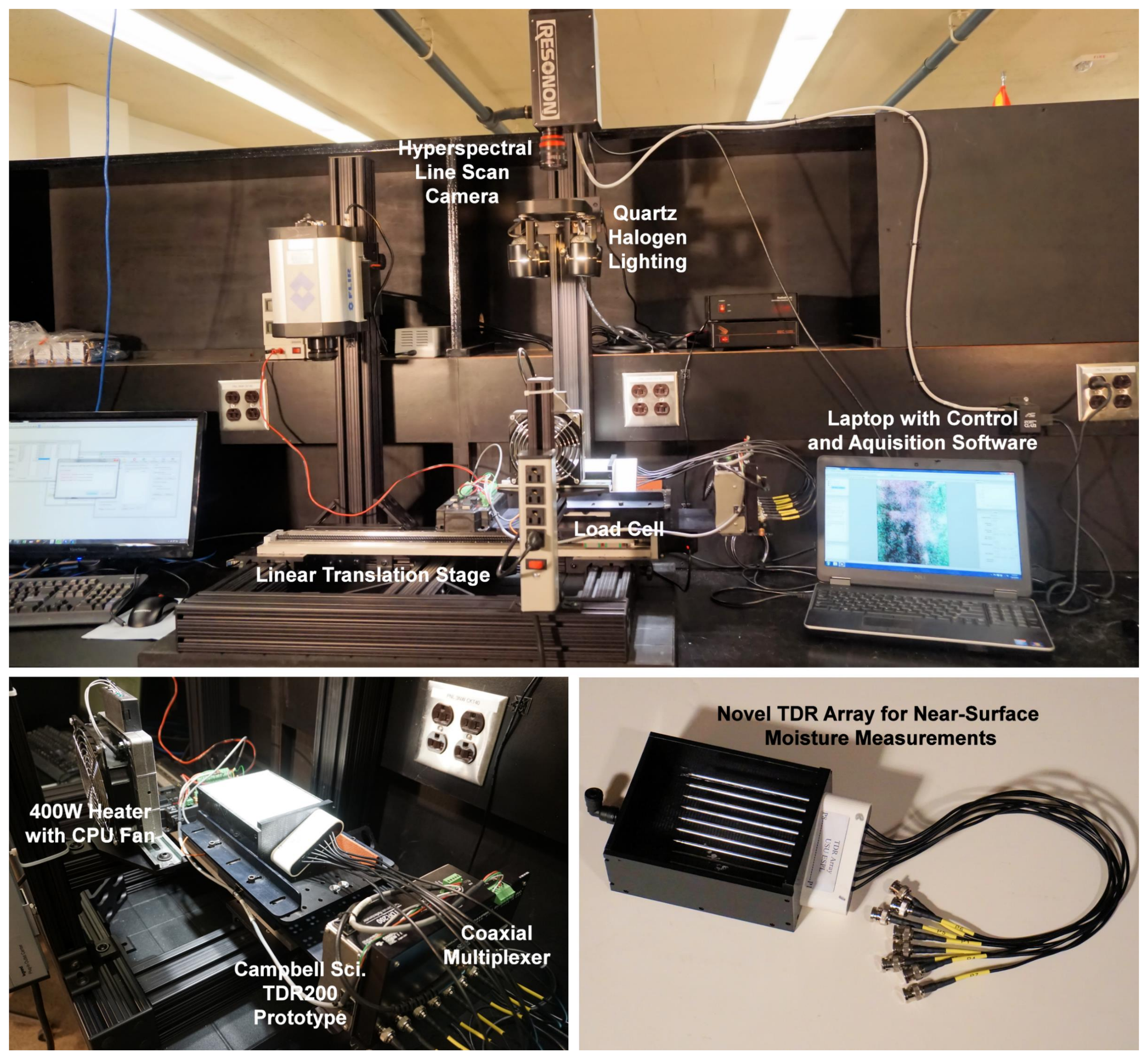

Figure 1: Experimental setup with close-up views of the sample box (during acquisition the sample moves relative to the steady camera).

- After scanning, the physically-based *Sadeghi et al. (2015)* model for near-surface soil moisture estimation from shortwave infrared reflectance was applied to generate time-lapse surface moisture distribution maps (Fig.3):

$$\theta/\theta_s = [(r - r_d)/(r_s - r_d)]$$

where θ is the actual water content, θ_s is saturated water content, r is the transformed reflectance $[1\text{-R}]^2/2\text{R}$ with R as the spectral reflectance at 1650 nm, r_d and r_s are the transformed reflectance of dry and saturated soil, respectively.

Preliminary Results

- As a preliminary test of the measurement system and the TDR array we conducted evaporation experiments with a coarse (silica sand) and fine textured (silty clay) soil, respectively.
- Figure 2 depicts series of average surface reflectance spectra measured during evaporative drying of silica sand and silty clay. A decrease in surface moisture content results in an increase in surface reflectance, which is more pronounced for silica sand because SiO_2 particles tend to reflect a larger portion of the incident electromagnetic radiation when compared to clays. The spectra show a strong correlation between reflectance and moisture content, which can be capitalized on for RS of surface moisture (*Lobel and Asner, 2002*).

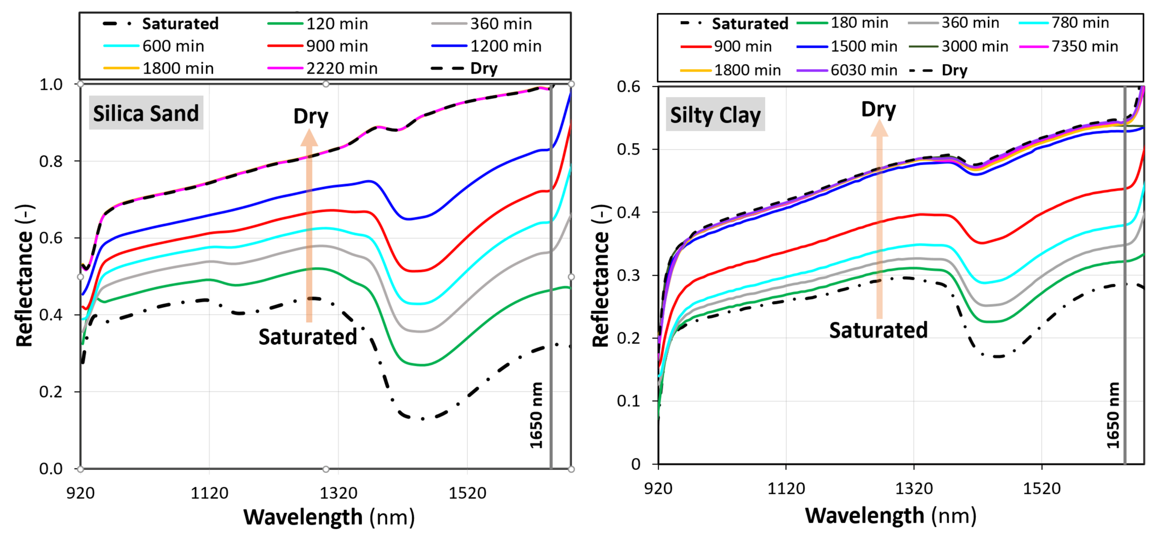

Figure 2: Average reflectance spectra measured during evaporative drying for silica sand and silty clay.

- Figure 3 shows surface soil moisture evolution during drying of the silty clay. The moisture content that was retrieved with the *Sadeghi et al. (2015)* model exhibits significant spatial variability, despite relatively uniform bulk density and atmospheric conditions.

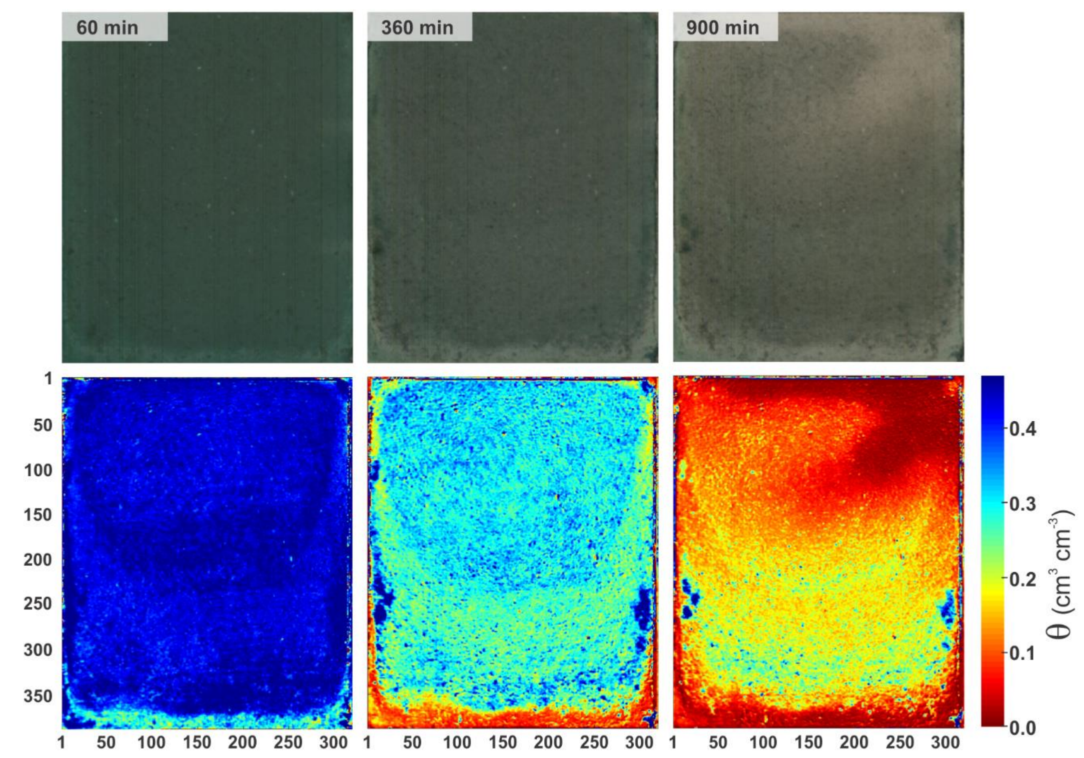

Figure 3: Surface soil moisture distributions of the silty clay at different stages of evaporative drying.

- Figures 4 and 5 depict surface and near-surface soil moisture dynamics directly measured with the TDR array and estimated from reflectance for silica sand and silty clay. As expected, there are significant moisture variations with depth. However, there is a disconnect between surface moisture and TDR-measured water contents even for the sensor recording at 0.75 cm depth.

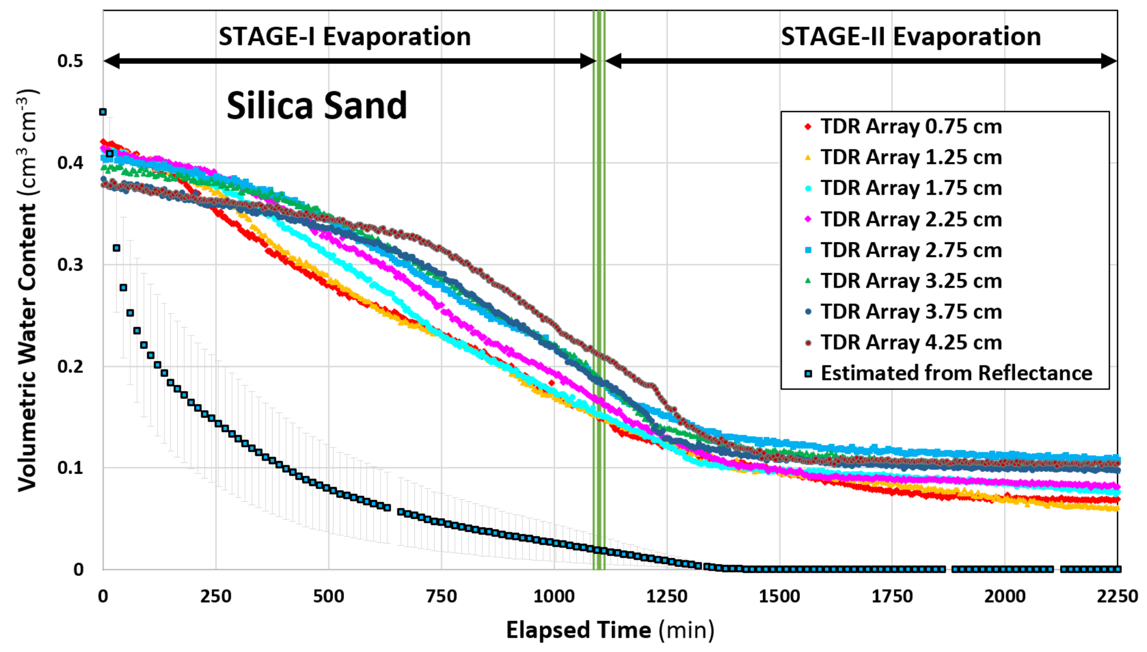

Figure 4: Surface and near-surface soil moisture dynamics measured with the TDR array and estimated from reflectance for silica sand.

Preliminary Results - Continued

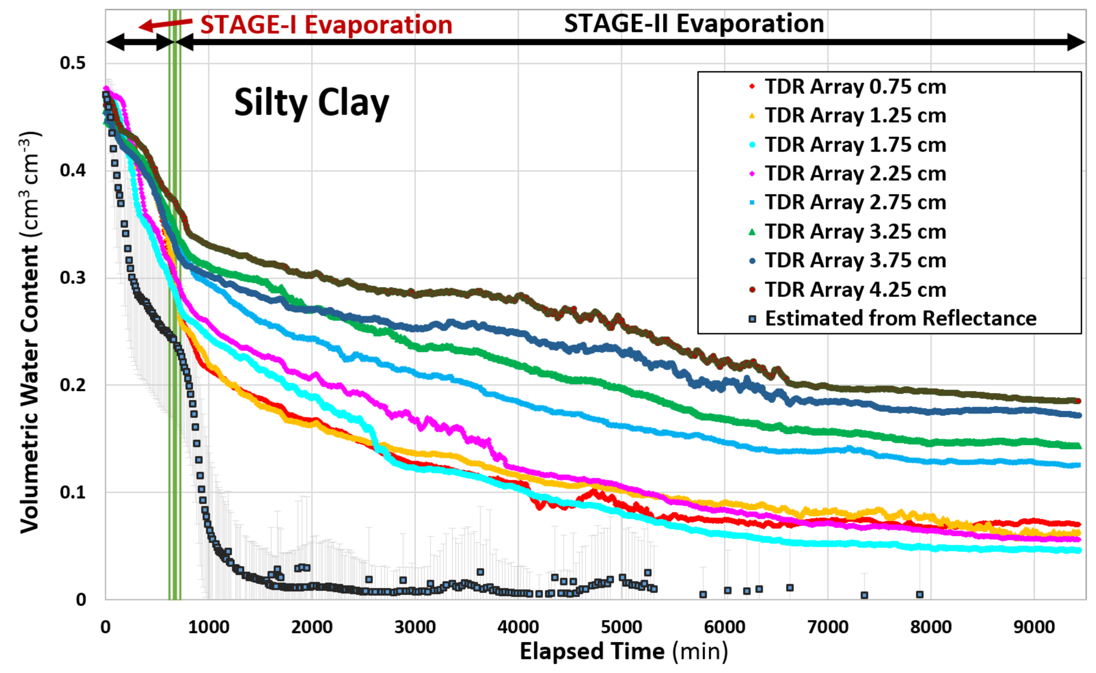

Figure 5: Surface and near-surface soil moisture dynamics measured with the TDR array and estimated from reflectance for silty clay.

- Figure 6 depicts distinct exponential relationships between surface moisture contents estimated from reflectance and evaporation rates determined from load cell data.

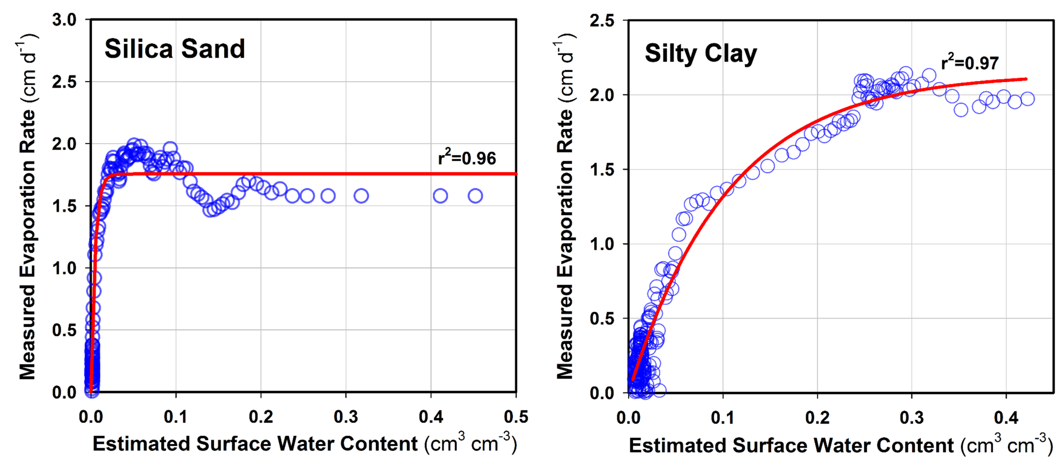

Figure 6: Relationships between estimated surface moisture content and measured evaporation rate for silica sand (left) and silty clay (right).

Conclusions and Ongoing Work

- The newly developed TDR array provides spatially highly resolved (5 mm) near-surface moisture measurements, not achievable with off-the-shelf moisture sensing technology. After some calibration adjustments and further testing the sensor will be a viable option for ground truth calibration of airborne and satellite soil moisture RS platforms.
- Clearly more data for a wide range of soil textures are needed to better understand the intrinsic relationships between surface reflectance and near-surface soil moisture and to develop advanced physically-based models applicable for airborne and satellite RS. A comprehensive measurement campaign is underway.
- The strong correlation between the surface moisture content obtained from surface reflectance measurements and soil evaporation rates points to the potential for development of new RS evaporation techniques.

References

Sadeghi, M., S.B. Jones, W.D. Philpot. 2015. A linear physically-based model for remote sensing of soil moisture using short wave infrared bands. Remote Sens. Environ. 164, 66–76.

Lobell, D.B., Asner, G.P., 2002. Moisture effects on soil reflectance. Soil Sci. Soc. Am. J. 66, 722–727. doi:10.2136/sssaj2002.7220.

Acknowledgements

The authors gratefully acknowledge support from the National Science Foundation (NSF) under grant # 1521469 .