Evaluation of a Novel Optical Trapezoid Model for Estimation of Large-Scale Root Zone Soil Moisture Based on MODIS Satellite Observations and Reference Cosmic-Ray Measurements

THE UNIVERSITY OF ARIZONA

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

[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

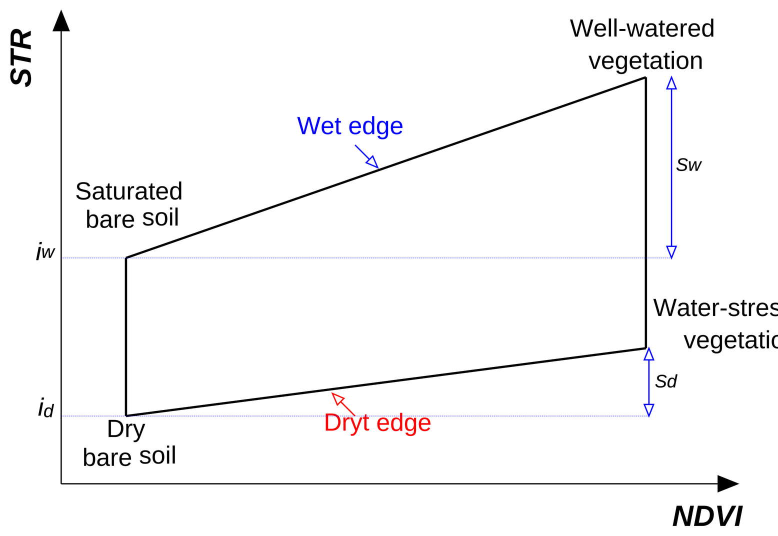
UtahStateUniversity

Background

- Recently, *Sadeghi et al.* (*2017*) proposed a physical "*optical trapezoid model*" (OPTRAM) for remote sensing of soil moisture (SM).
- OPTRAM is based on the pixel distribution within the shortwave infrared transformed reflectance (*STR*)-normalized difference vegetation index (*NDVI*) space, defined as:

$$W = \frac{\theta}{\theta_s} = \frac{i_d + s_d NDVI - STR}{i_d - i_w + (s_d - s_w) NDVI}$$

$$\begin{cases} STR_d = i_d + s_d NDVI \\ STR_w = i_w + s_w NDVI \\ W = \dfrac{STR - STR_d}{STR_w - STR_d} \end{cases}$$



- The advantage of the *STR-θ* space over the conventional triangle/trapezoid approach (*LST-θ* space) (*Carlson et al., 1994*) is that: (*1*) it only requires optical data; and (*2*) it can be universally parameterized for a given location because *STR-θ* is not affected by ambient atmospheric factors.
- However, the *STR-θ* space is sensitive to oversaturated pixels (due to ponding water) and hence occasionally yields W>1 (*Sadeghi et al., 2017*)
- To solve this issue and to obtain a robust model parameterization, we used long-term MODIS data and evaluated OPTRAM across regions with various climates, land-covers, and soil types for estimation of SM.
- Cosmic-ray neutron probe (CRNP) observations as well as satellite soil moisture products including SMAP, SMOS, and ASCAT were used to evaluate OPTRAM's accuracy. CRNPs exhibit a volume of influence similar to the size of a MODIS pixel.

Methodology

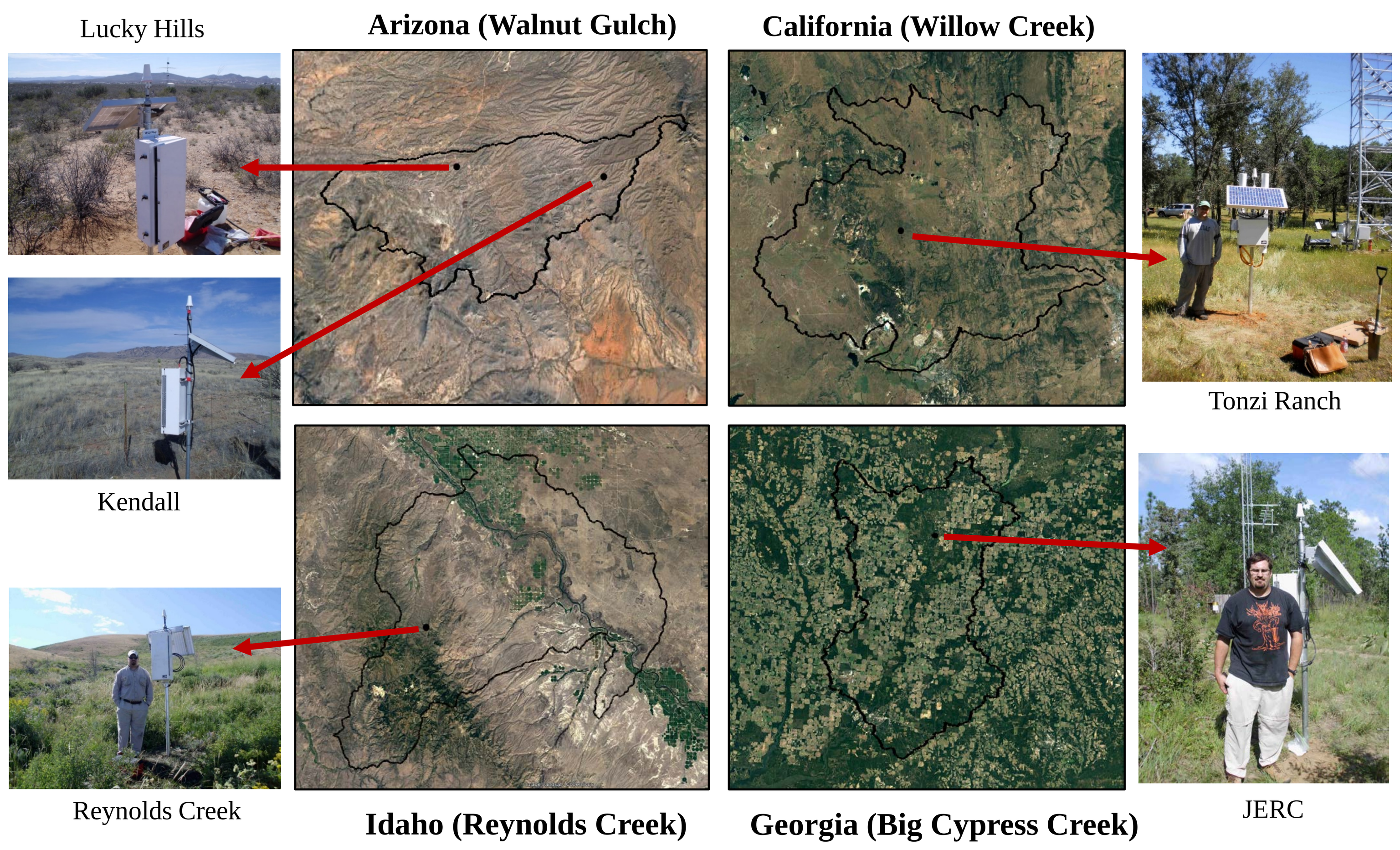
Test Regions

- 4 Watersheds in the U.S. with different climates, land covers, soil types were selected.

Ground-based soil moisture

- **Cosmic-ray neutron probe observations (CRNP)** were collected from the Lucky Hills and Kendal sites (Arizona), Tonzi Ranch (California), Reynolds Creek (Idaho), and JERC (Georgia) from 2011 to 2017.
- The *Franz et al. (2013)* framework was used to correct soil moisture (θ_v) for all hydrogen sources. i.e., lattice water (θ_{lw}), atmospheric water vapor, and soil organic matter water (θ_{soceq}).

$$\theta_v = \left[\frac{0.0808}{\left(\frac{N_{pih}}{N_0}\right) - 0.372} - 0.115 - \theta_{lw} - \theta_{soc_{eq}} \right] \rho_b$$



Methodology - Continued

Satellite data

- ***MODIS***: Long-term land surface reflectance products (MOD09A1, 500m, 8-day) from 2001 to 2017 were used. Bands 1 (Red), 2 (NIR) and 7 (SWIR) were utilized to define STR-NDVI space.
- ***SMAP*** level-3 surface soil moisture product (L3_SM_P, descending 6:00 a.m.; 36 km; daily)
- ***ASCAT*** soil moisture product (EUMETSAT H109, H110; 12.5 km; daily)
- ***SMOS*** level-3 soil moisture product (Version 3.0, 6:00 a.m.; 25 km, daily)

Bias reduction and CDF Matching

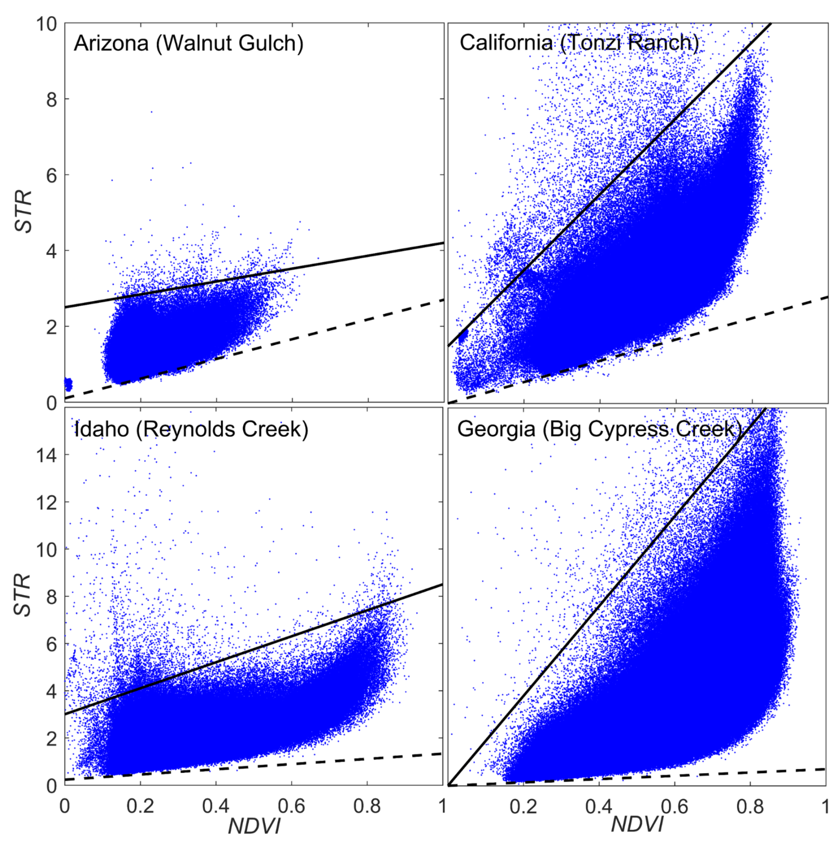
- The Cumulative Distribution Function (CDF) matching method has been recommended for reducing systematic biases between two datasets, e.g., satellite-based estimates and in situ measurements.
- A simple strategy (*Reichle and Koster, 2004*) was applied to match the CDF of estimated soil moisture to that of the in situ CRNP observations based on a transformation to consistent normal deviates

$$CDF_{ground}(x') = CDF_{satellite}(x)$$

Results

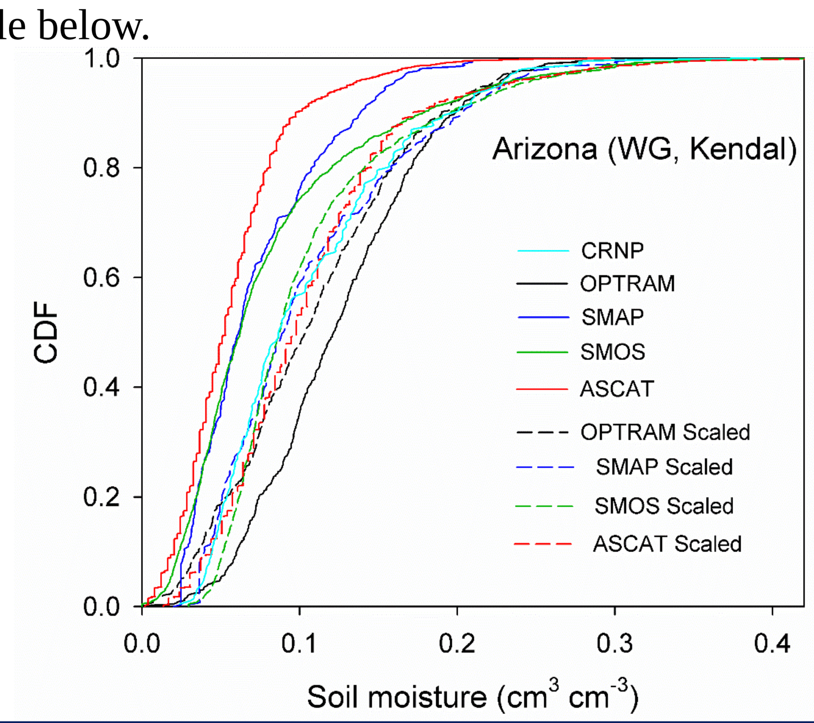
Model Parametrization

- A nearly trapezoidal shape is formed for all four watersheds.
- A universal parametrization with long-term MODIS data was performed to derive dry and wet edge parameters. The figure below depicts the obtained STR-θ spaces and optimized edges.



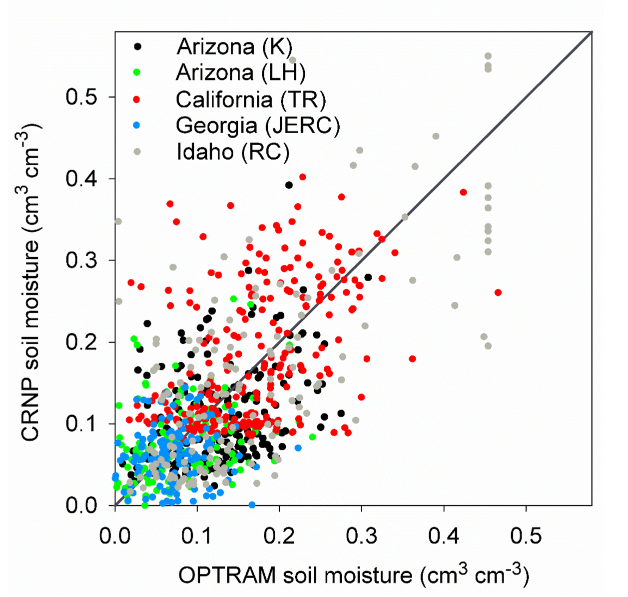
CDF Matching

- CDFs based on CRNPs and the original and rescaled soil moisture estimates from OPTRAM, SMAP, SMOS, and ASCAT for Kendal CRNP site (AZ) are depicted as an example below.



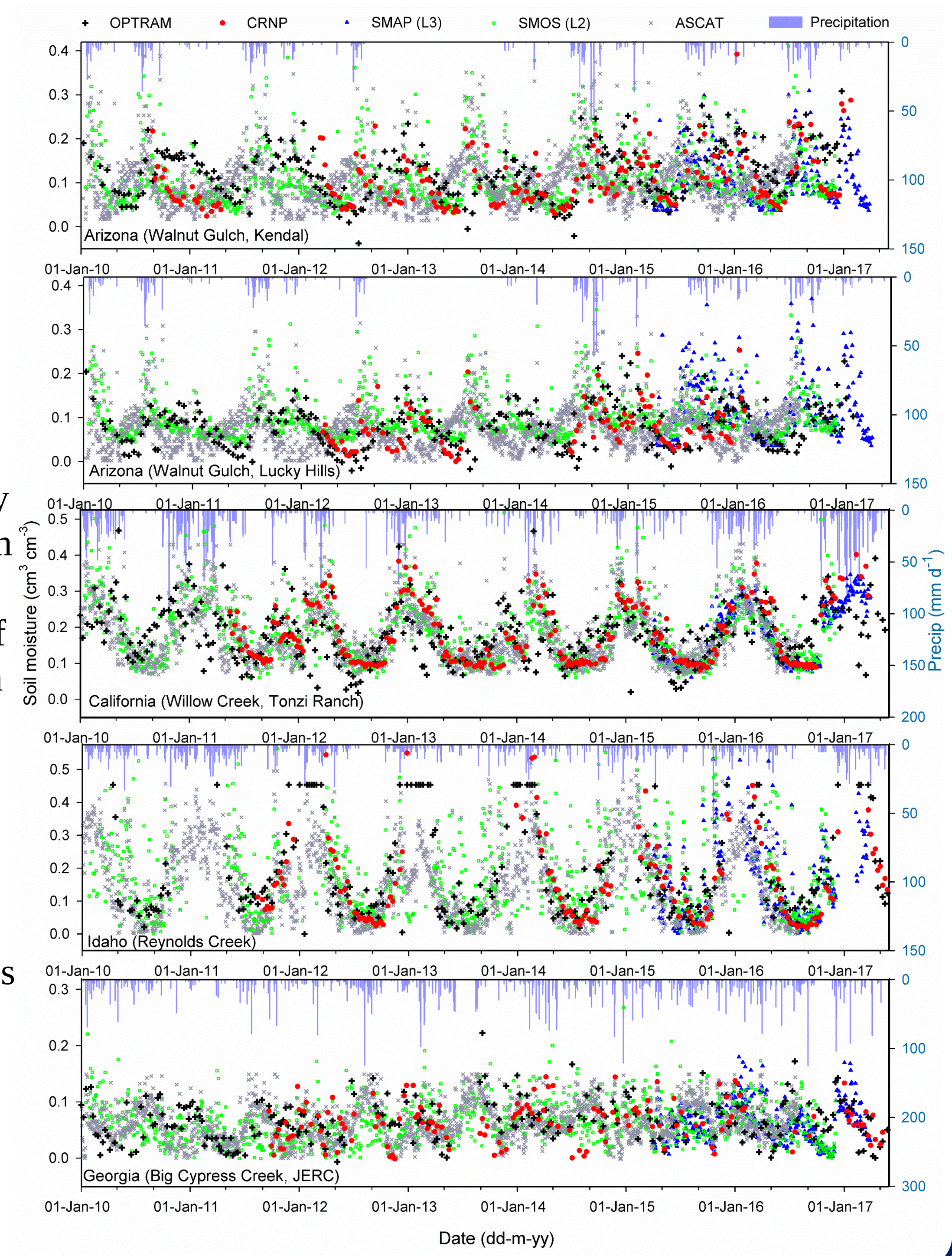
Results - Continued

- Scatterplots comparing rescaled estimated soil moisture (OPTRAM) and CRNP based measurements for the five selected sites indicate a good performance of OPRAM.
- The accuracy of OPTRAM was different for the four selected sites with a mean RMSE 0.07 cm^3 cm^{-3} (see the Table), which is reasonable for the optical domain and the large number of analyzed MODIS images.



Metrics	**Arizona** (Lucky Hills)	**Arizona** (Kendal)	**California** (Tonzi Ranch)	**Idaho** (Reynolds Creek)	**Georgia** (JERC)
R	0.32	0.36	0.46	0.70	0.10
RMSE	0.065	0.072	0.085	0.083	0.050
Bias	-0.015	-0.036	0.012	0.011	-0.007
ubRMSE	0.0638	0.0624	0.0848	0.0822	0.0501

- OPTRAM yields SM dynamics similar to those of CRNPs and microwave satellites during 2015 to 2017.



- Like microwave satellites, OPTRAM responds to SM dynamics as well as precipitation events quite well.
- Although CRNPs measure the effective SM within a wide range, the discrepancy between sensing depth of optical signals and measurement depth of cosmic-ray could be a source of error.
- Another source of error could be high biomass, which leads to high uncertainty in CRNP data. A biomass correction would be required, especially for the JERC site in Georgia.

Conclusion

- The obtained results indicate reasonable accuracy of OPTRAM across regions with different climates, land covers, and soil types for large-scale estimation of soil moisture.
- OPTRAM yields similar SM trends as SMAP, SMOS, and ASCAT soil moisture products.
- CRNP observations could be an option to fill the scale gap between point measurements and satellite-based estimations of soil moisture.

Reference

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The authors gratefully acknowledge support from the National Science Foundation (NSF) under grant No. 1521469.