A New Optical Trapezoid Model for Remote Sensing of Soil Moisture

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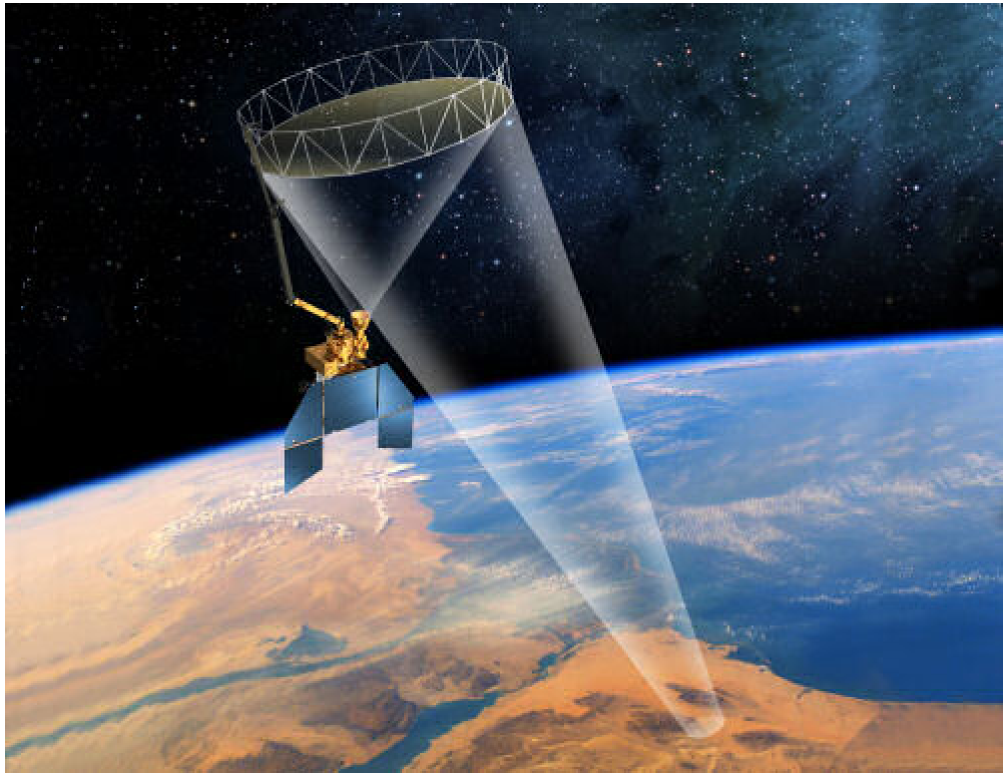
- EM radiation in various wavelengths is correlated to soil moisture.



Microwave [0.5-100 cm]

- ✓ High penetration depth.
- × Low spatial resolution.

Downscale

Optical [0.4-2.5 µm]

Thermal [3.5-14 µm]

- × Low penetration depth.
- ✓ High spatial resolution.

Thermal-Optical Trapezoid Model (TOTRAM)

Traditional Model

- ✓ **Linear *LST-θ* relationship:**

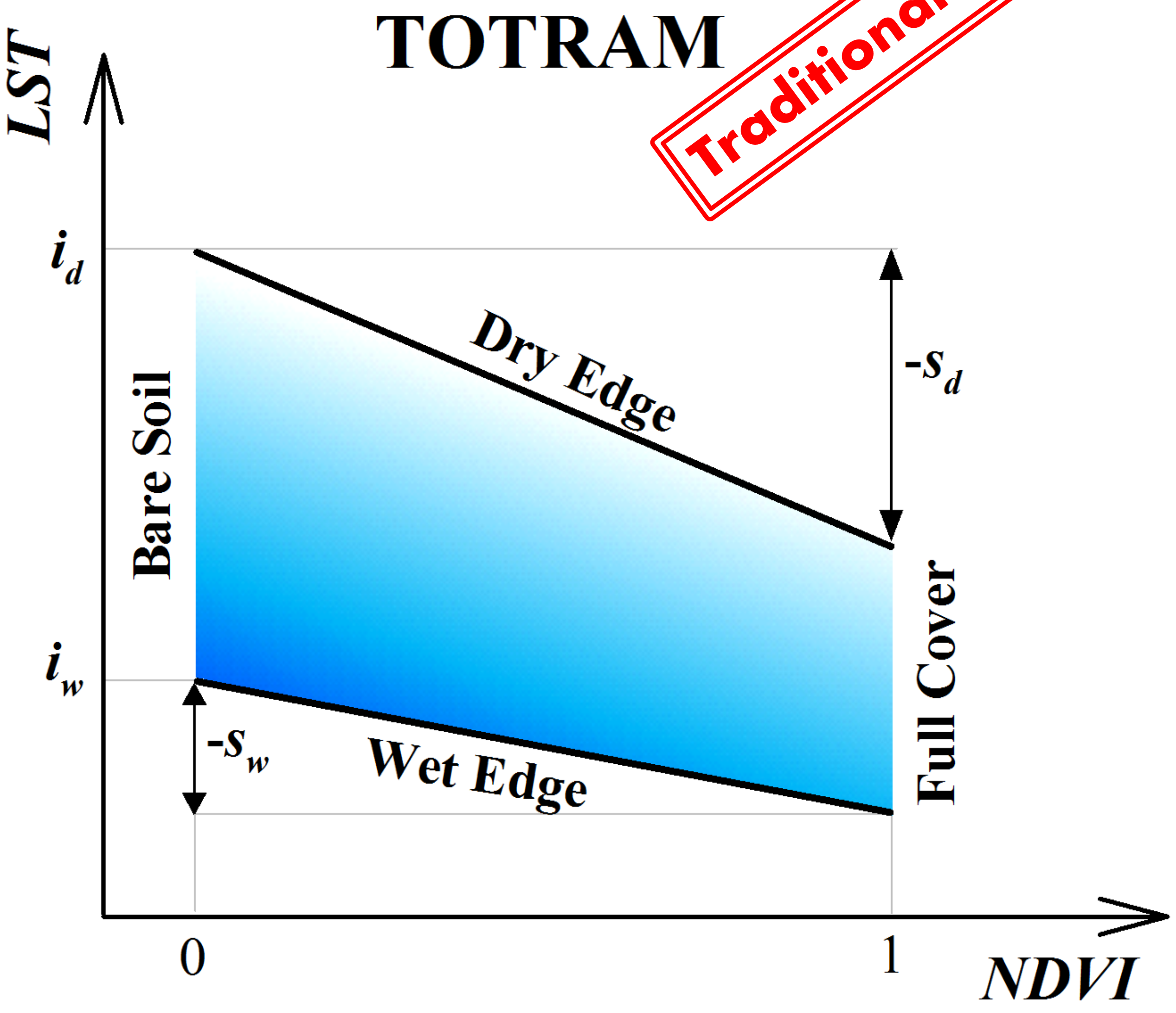
$$W = \frac{\theta - \theta_d}{\theta_w - \theta_d} = \frac{LST_d - LST}{LST_d - LST_w}$$

- ✓ **Linear dry and wet edges:**

$$LST_d = i_d + s_d NDVI$$
$$LST_w = i_w + s_w NDVI$$

- ✓ **TOTRAM:**

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



Two main limitations of TOTRAM:

1) TOTRAM cannot be used for satellites with no thermal band (e.g. Sentinel-2).

2) Beside soil moisture, *LST* depends on ambient environmental factors (e.g. air temperature, wind speed). TOTRAM needs to be parameterized for each individual image.

Core idea?

Reflectance-soil moisture relationship is not significantly affected by environmental factors.

So, a universal parameterization is feasible.

Can we resolve both limitations by proposing an "Optical" Trapezoid model?

Optical Trapezoid Model (OPTRAM)

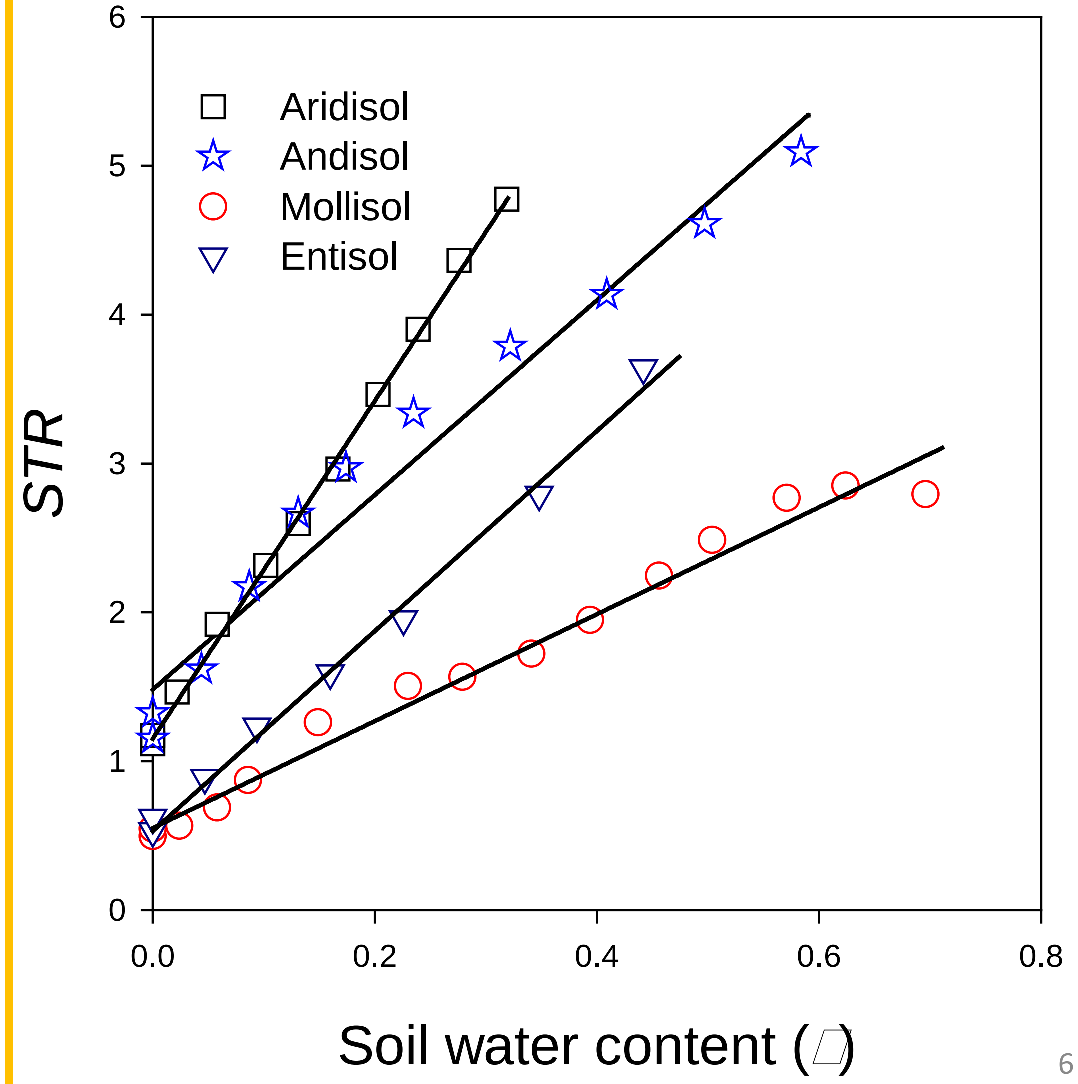
OPTRAM is based on a linear physically-based model:

$$W = \frac{\theta - \theta_d}{\theta_w - \theta_d} = \frac{STR - STR_d}{STR_w - STR_d}$$

where: $$STR = \frac{(1 - R_{SWIR})^2}{2R_{SWIR}}$$

***R*$_{SWIR}$: Reflectance at SWIR**
***STR*: Transformed reflectance at SWIR**

Sadeghi et al. 2015. A linear physically-based model for remote sensing of soil moisture using short wave infrared bands. *Remote Sensing of Environment*. 164:66-76.



Optical Trapezoid Model (OPTRAM)

- ✓ Linear ***STR*-*θ*** relationship at a given ***NDVI***:

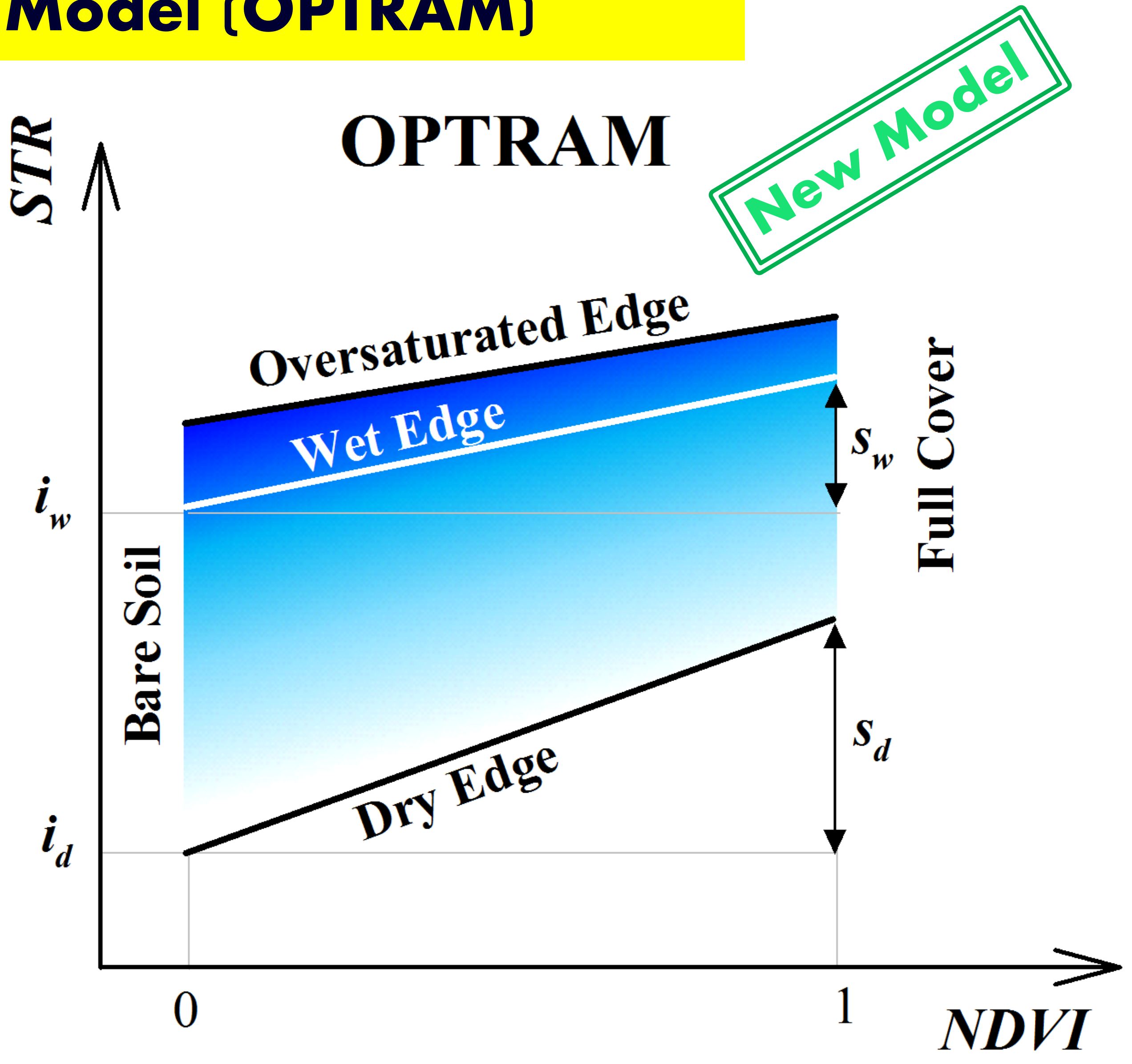
$$W = \frac{\theta - \theta_d}{\theta_w - \theta_d} = \frac{STR - STR_d}{STR_w - STR_d}$$

- ✓ Linear dry and wet edges:

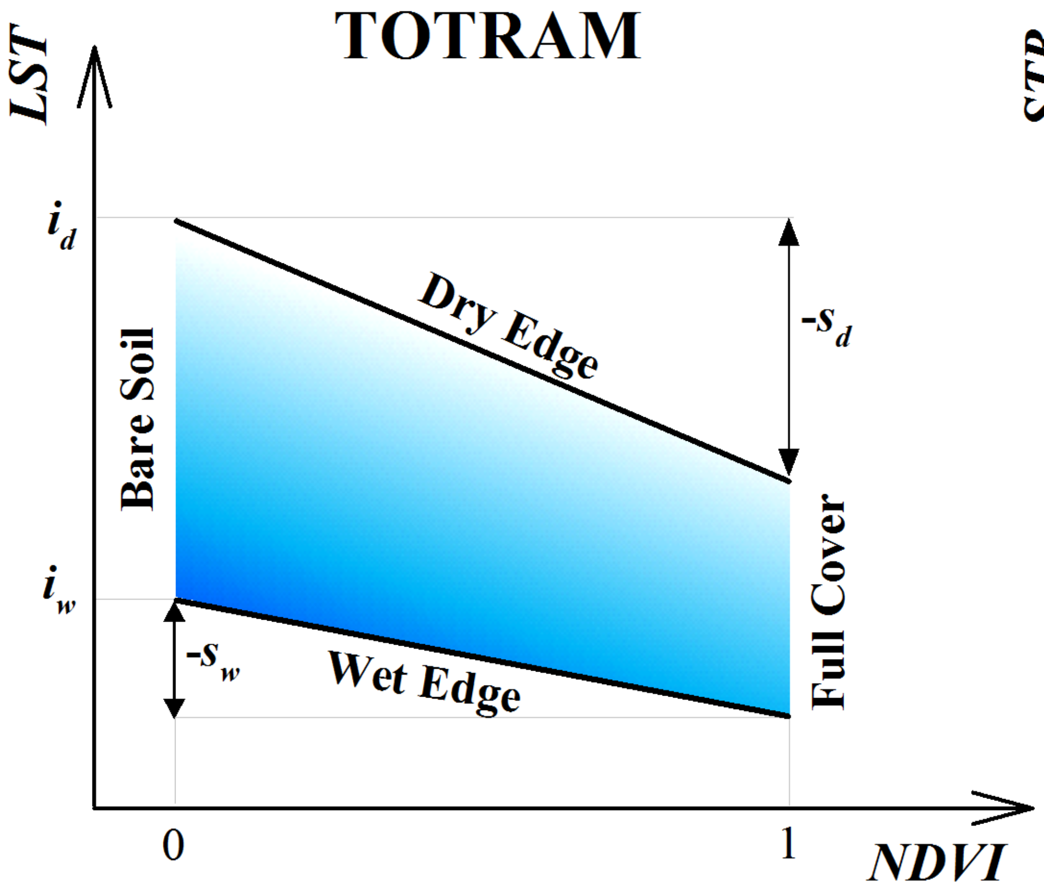
$$STR_d = i_d + s_d NDVI$$
$$STR_w = i_w + s_w NDVI$$

- ✓ OPTRAM:

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

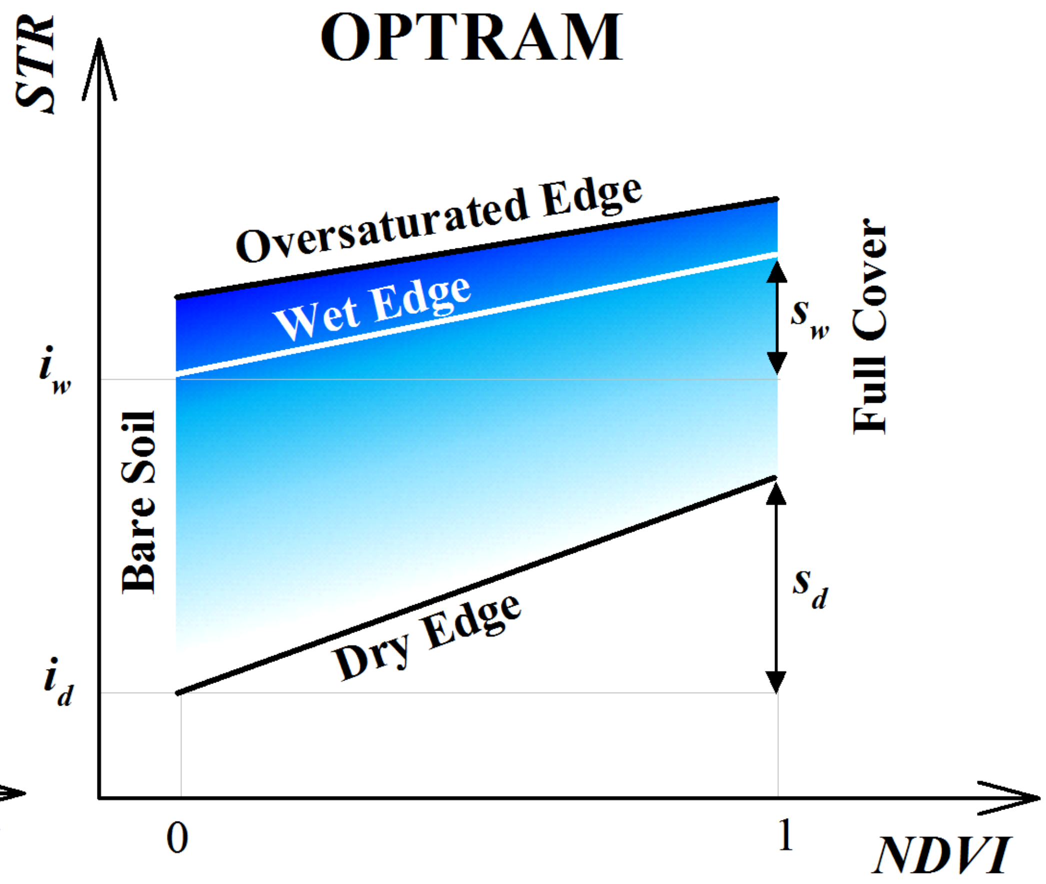


Traditional Model



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

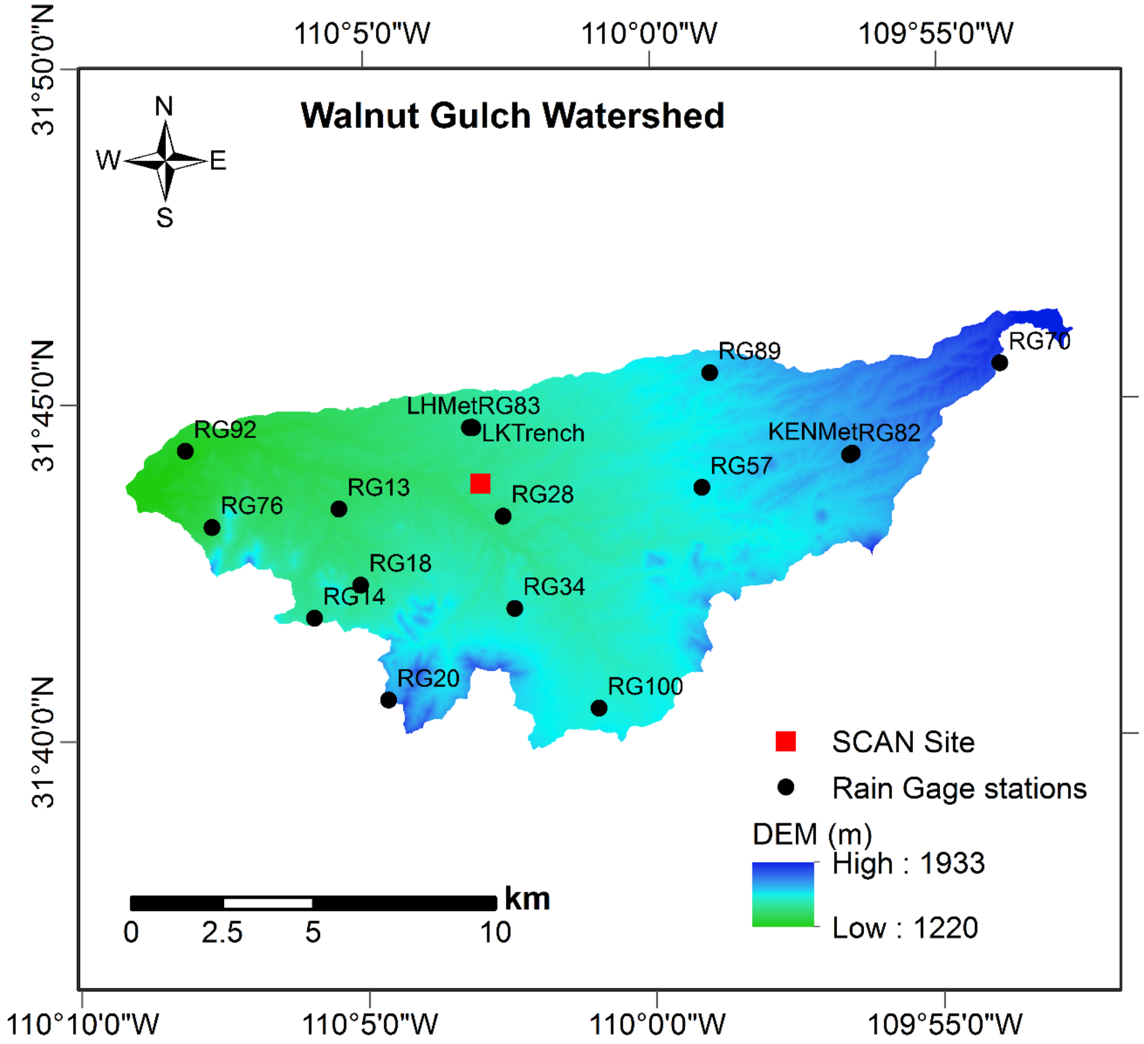
New Model



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

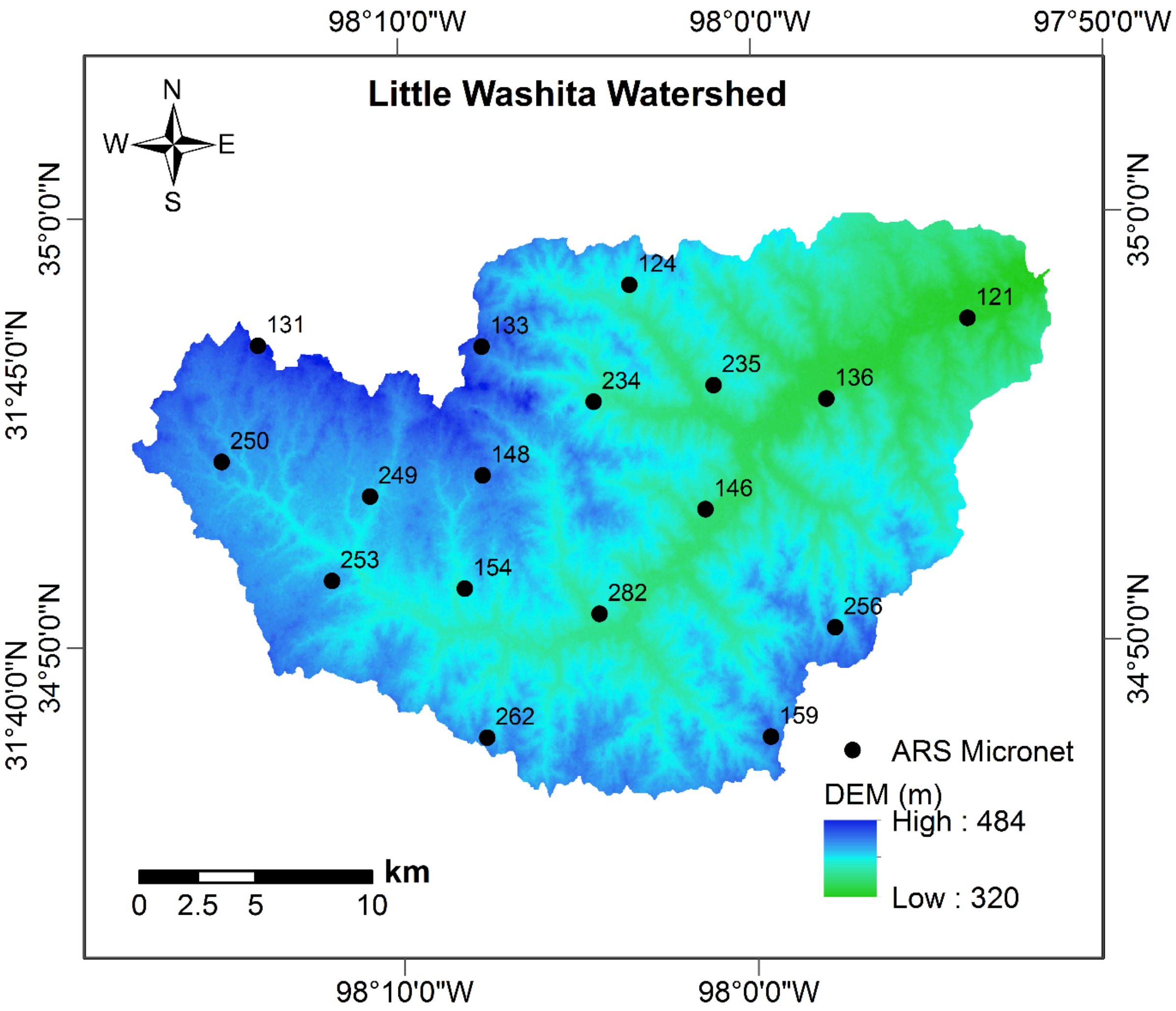
Study Area

Arizona



1 SCAN site; 15 rain-gauge stations

Oklahoma

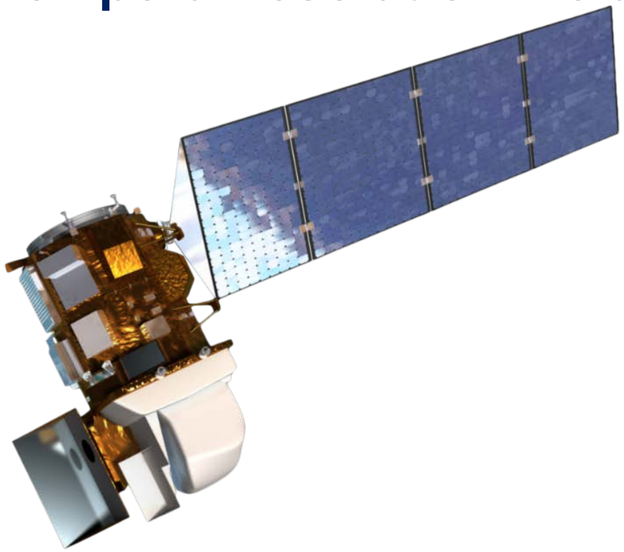


17 USDA-ARS micro-net stations

Satellite Imagery

Landsat-8

NASA (11 February 2013)
9 Optical and 2 thermal bands
Spatial resolution: 30-100 m
Temporal resolution: 16 days



12 images in WG
5 images in LW
2015-2016

Sentinel-2

ESA (23 June 2015)
13 optical bands
Spatial resolution: 10 to 60 m
Temporal resolution: ~10 days

17 images in WG
4 images in LW
2015-2016

Model Parameterization

- ❑ **Feasibility of universal parameterization was tested incorporating all images.**

- ❑ **Two scenarios were considered:**

1) Local calibration:
Edges were determined visually.
***W* was calibrated with *θ* data.**

2) No local calibration:
Edges were determined by fitting.
***W* was converted to *θ* using measured min and max *θ*.**

TOTRAM:

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

OPTRAM:

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

Normalized soil moisture:

$$W = \frac{\theta - \theta_d}{\theta_w - \theta_d}$$

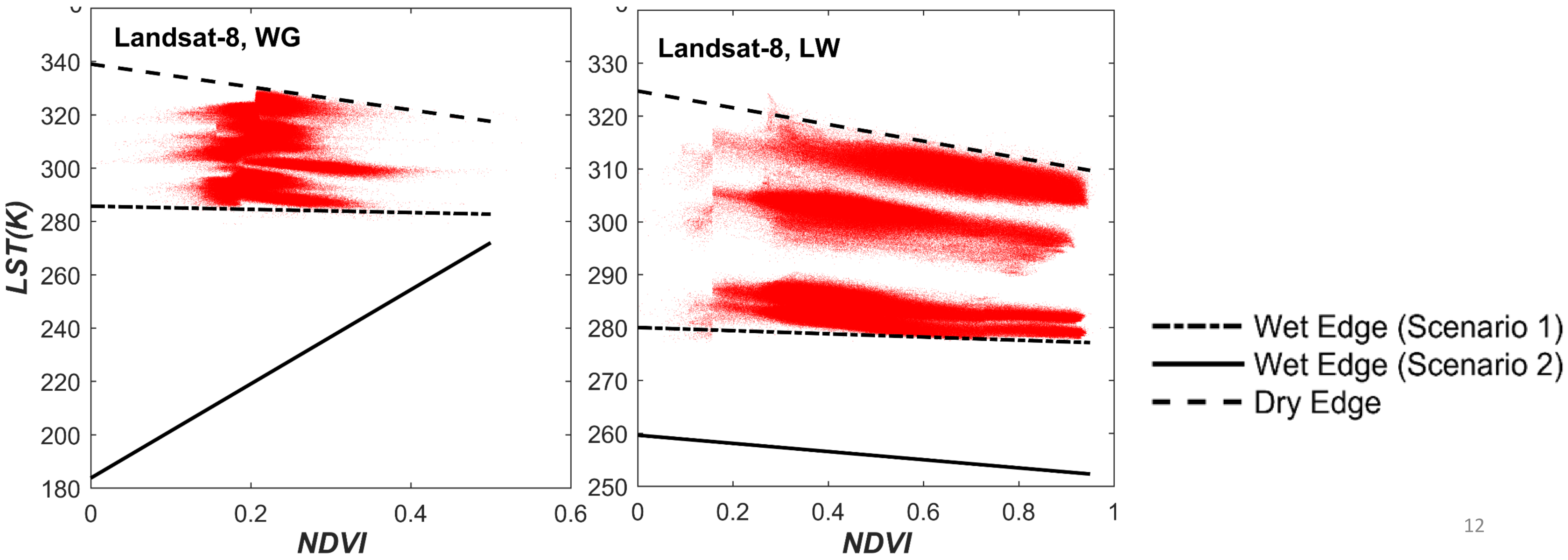
Traditional Trapezoid

- ❑ **A nearly trapezoidal shape is formed:**

LST **is sensitive to** ***θ*** **in a broad range of fractional vegetation covers.**

- ❑ **Integrated trapezoid consists of several separate smaller trapezoids:**

LST **depends on ambient environmental factors besides soil moisture.**



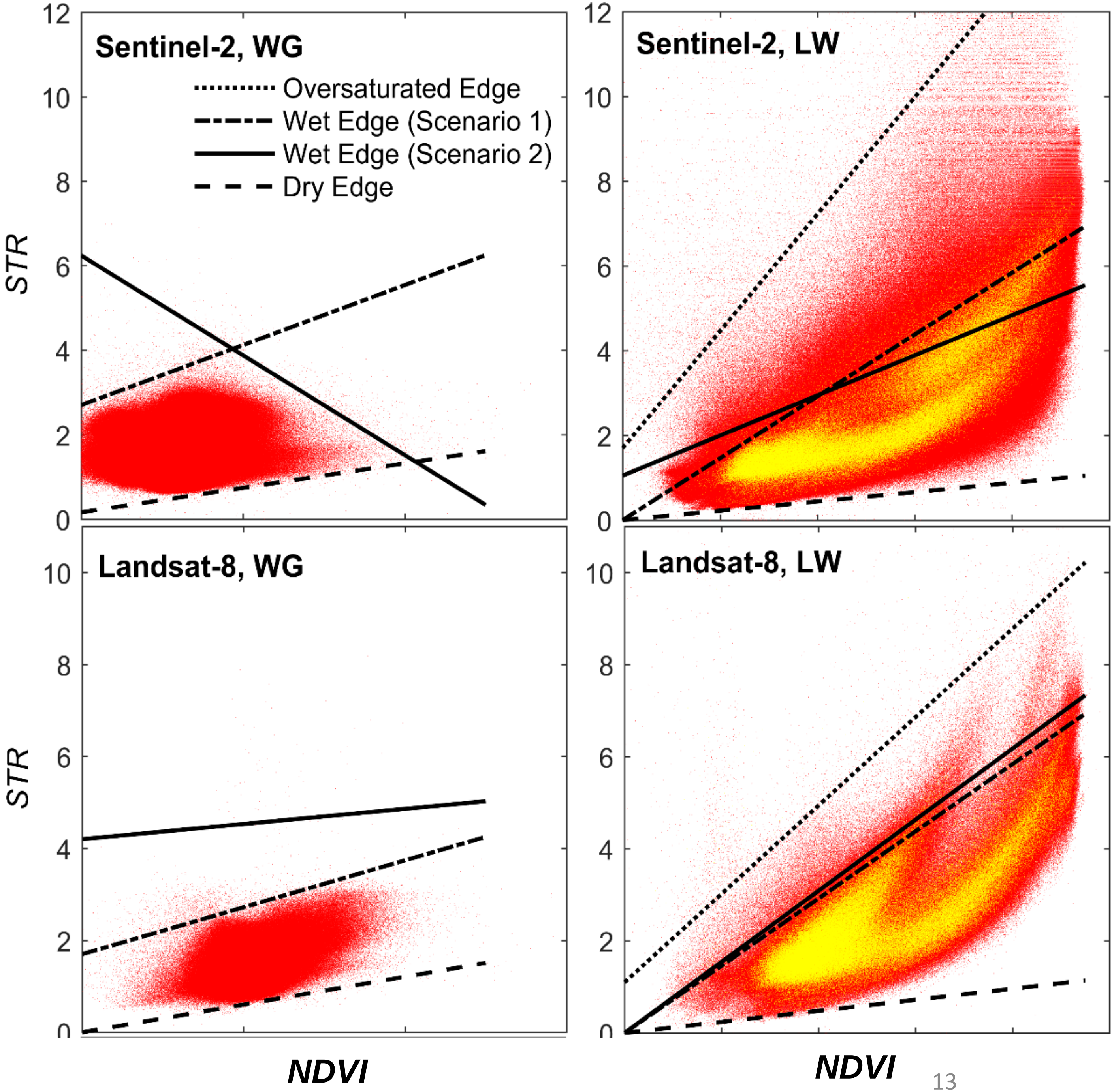
New Trapezoid

- ❑ **A nearly trapezoidal shape is formed:**

***STR* is sensitive to *θ* even in densely vegetated soils.**

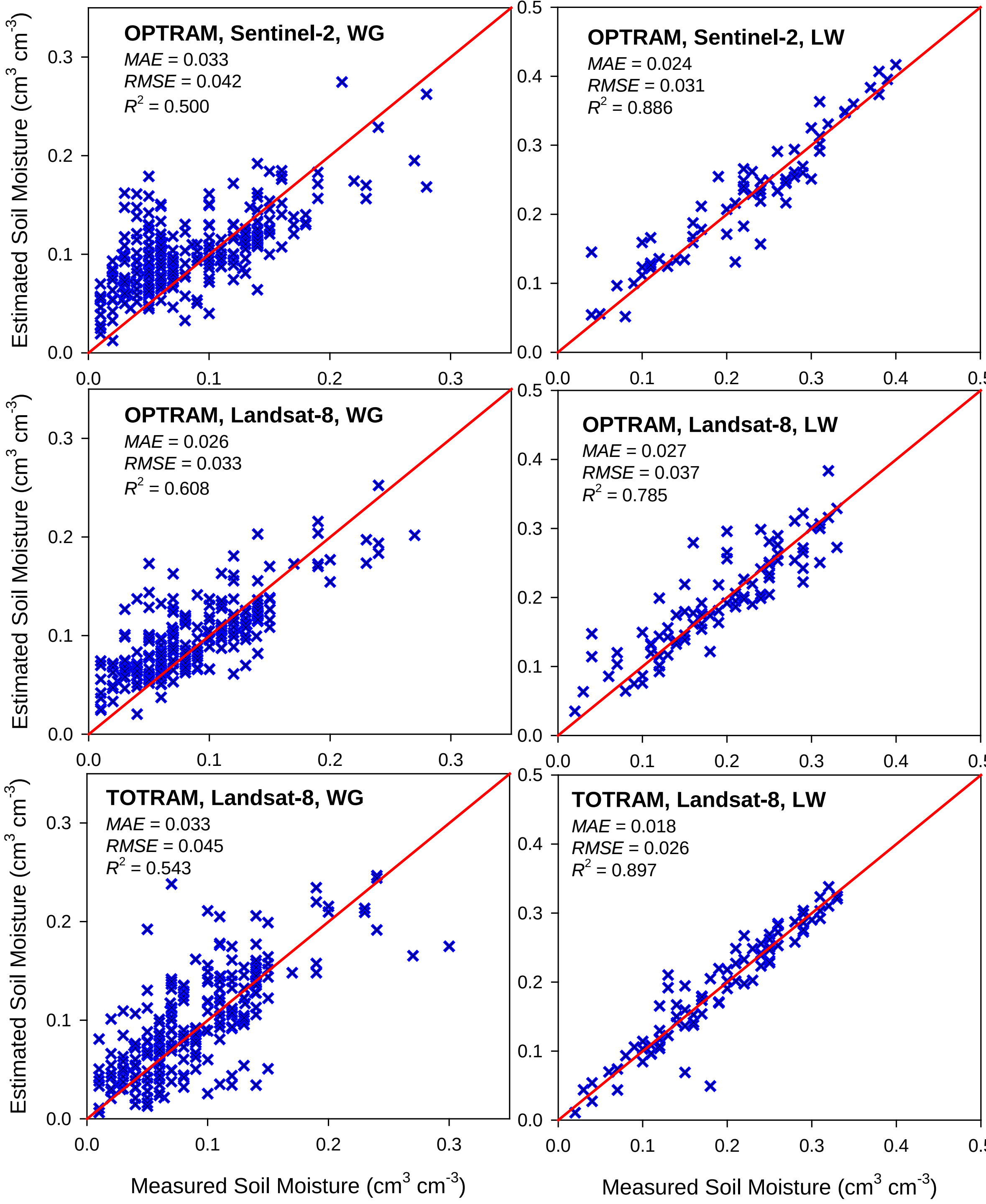
- ❑ **Trapezoids are visually similar:**

Universal calibration is feasible.



Overall Accuracy (with local calibration)

- TOTRAM and OPTRAM showed similar accuracy.
- Both models, when calibrated, yield reasonable estimates (error < 4%)

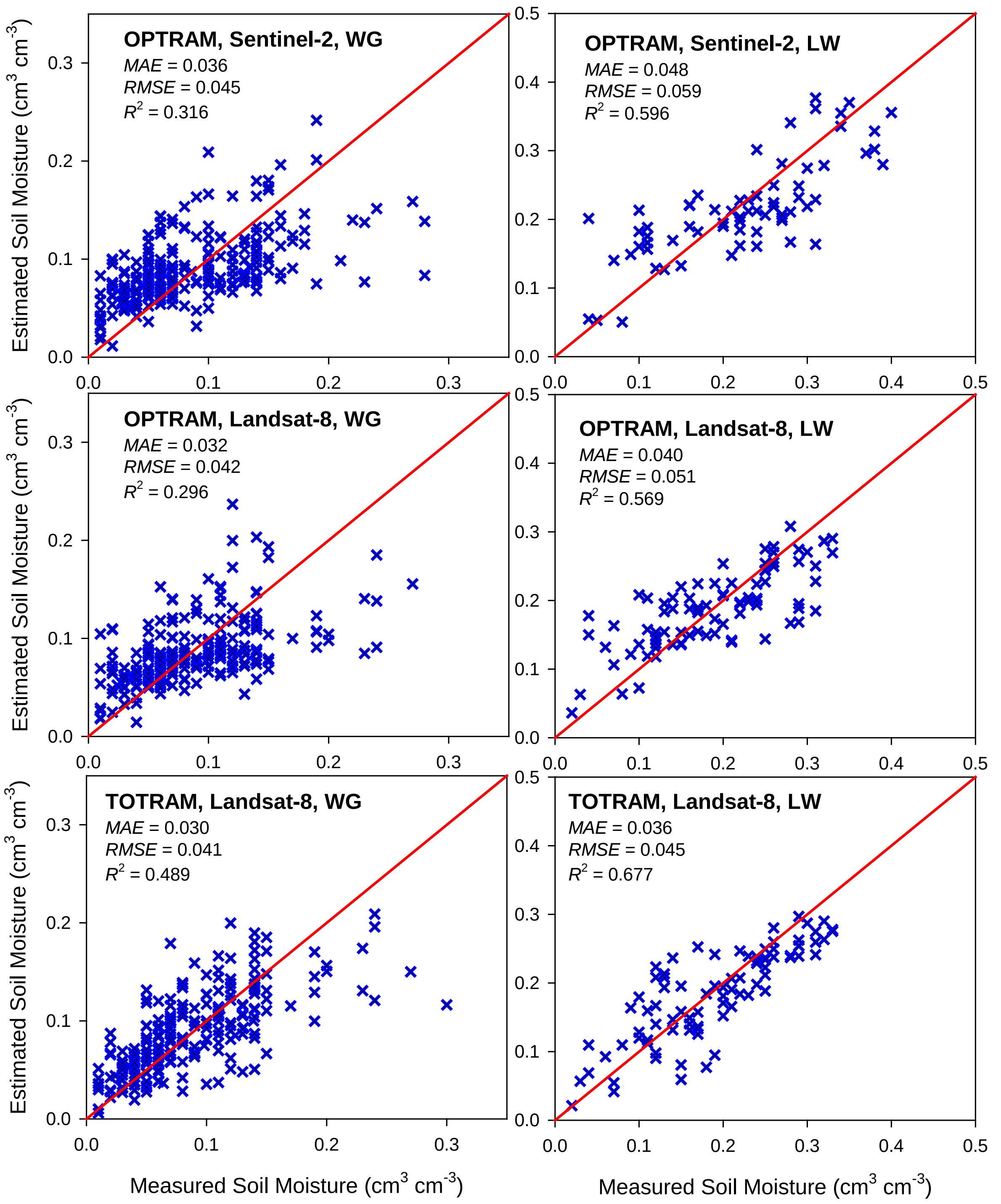


Overall Accuracy (No local calibration)

- ❑ Without local calibration, both models still yield reasonable estimates (error ~ 4-5%)

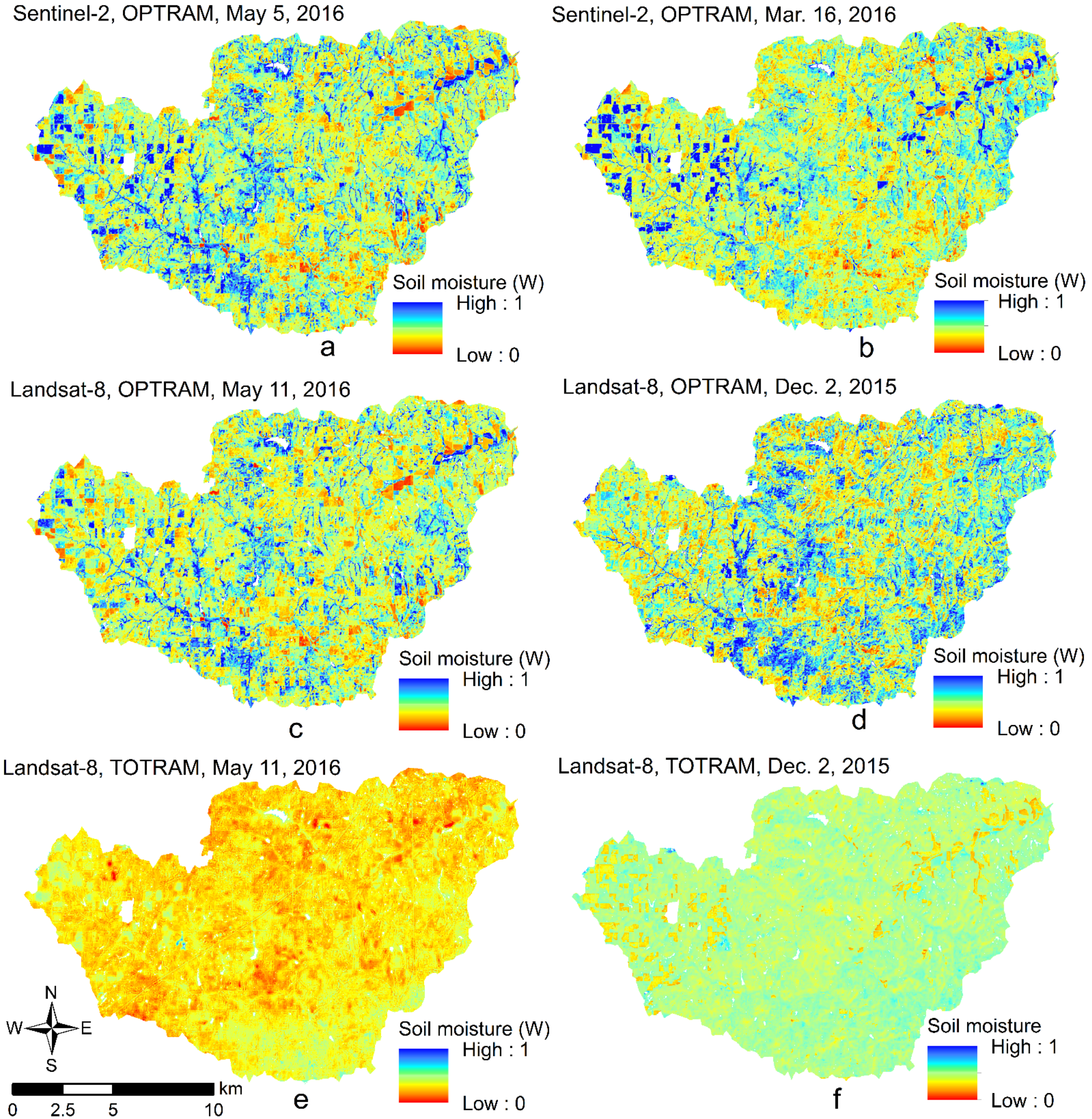
- ❑ Scattering is due to approximations:

1) Linear *LST-θ* relationship at a given *NDVI*.
2) Linear *STR-θ* relationship at a given *NDVI*.
3) Linear *LST-NDVI* relationship at a given *θ*.
4) Linear *STR-NDVI* relationship at a given *θ*.



Soil Moisture Maps

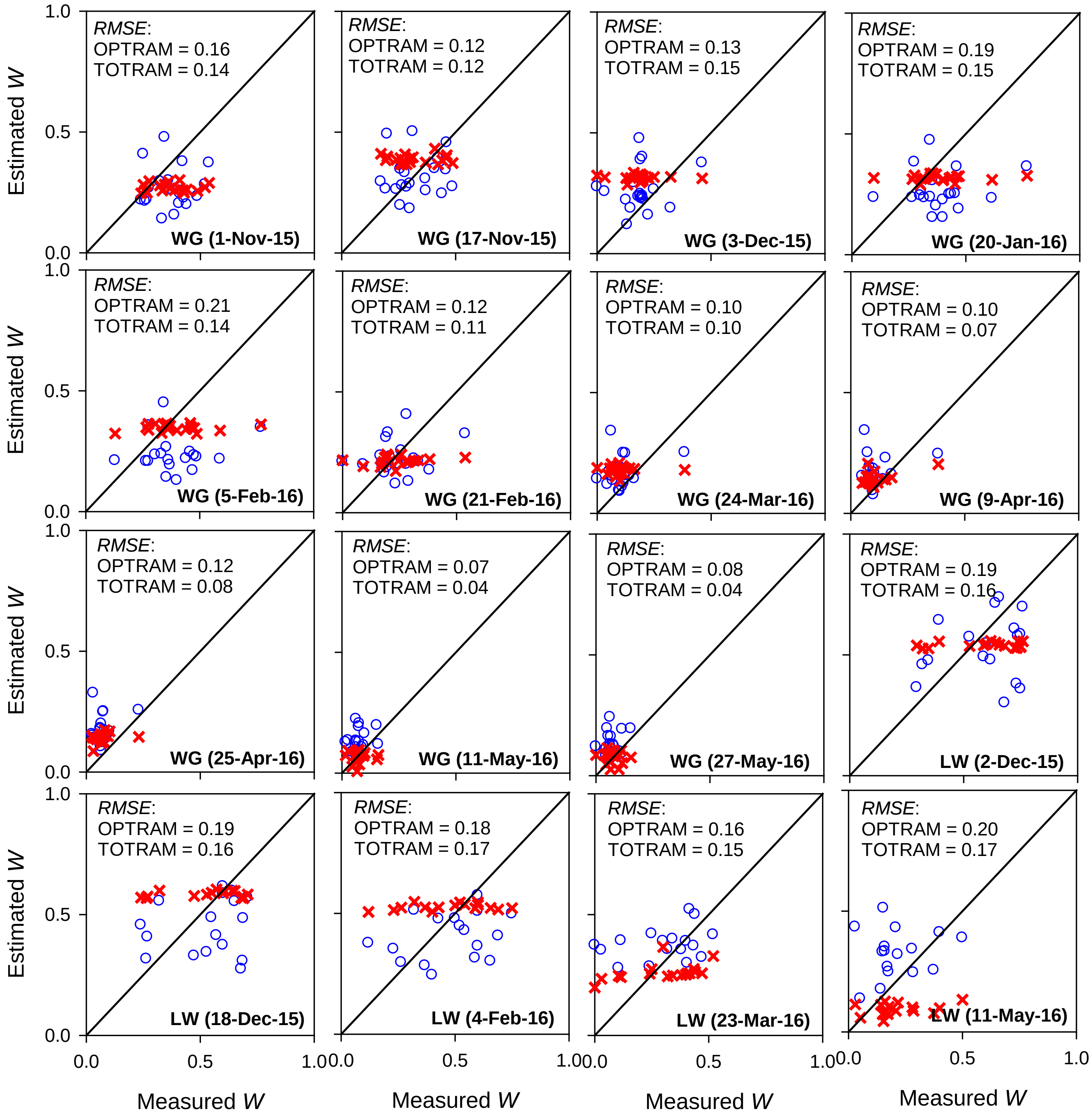
- ❑ **TOTRAM yielded *W* in a narrow range.**
- ❑ **OPTRAM maps better match the DEM. They show river network.**



Date-by-Date Comparison

- ❑ **TOTRAM failed in predicting spatial variability of soil moisture:**
Universal parameterization is not feasible.

- ❑ **OPTRAM successfully captured spatial variability of soil moisture:**
Universal parameterization is feasible.



Conclusions:

- OPTRAM resolves two limitations of TOTRAM.
- OPTRAM and TOTRAM overall accuracy is comparable.

Future Work:

- More extensive evaluations.
- Improving model accuracy and parameterization.

Reference:

Sadeghi, M., E. Babaeian, M. Tuller, S. B. Jones. 2017. The Optical Trapezoid Model: A Novel Approach to Remote Sensing of Soil Moisture Applied to Sentinel-2 and Landsat-8 Observations. ***Remote Sensing of Environment***, Accepted.

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Thanks for your Attention!