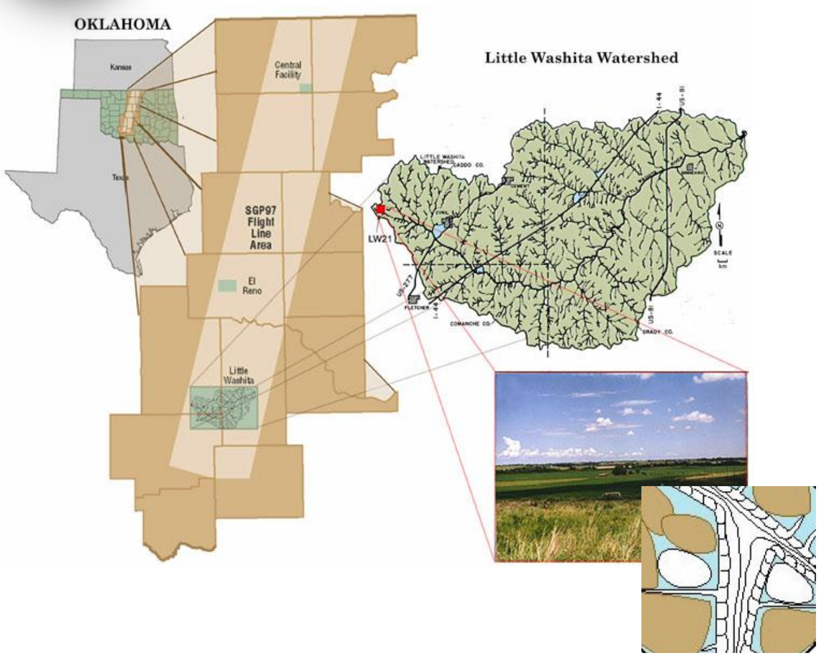
Partly supported by:

# Improving Multi-Scale Root Zone Soil Water Process Representation in Land Surface Models




**Binayak P. Mohanty**

**& Vadose Zone Group**

**Texas A&M University**

**Texas Drought Forum**

**Oct 22, 2012**

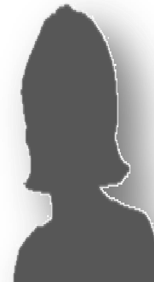
**http://vadosezone.tamu.edu/**

# Vadose Zone Research Group

Dr. Binayak P. Mohanty

Dr. Fabio Sartori

Dr. Joseph Pollacco



Dr. Itza Mendoza-Sanchez

Dr. Zhongyi Qu

David Hansen

Raghavendra Jana

Champa Joshi

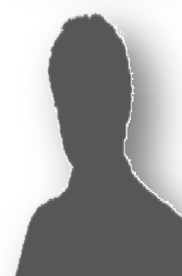
Bhavna Arora

Dipankar Dwivedi

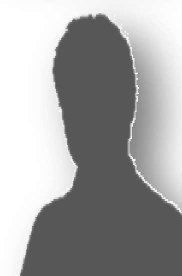
Sean Tolle

Yongchul Shin

Nandita Gaur



Taehoon Kwak



Sandeep Patil

# Soil Moisture Flow Below our Feet!

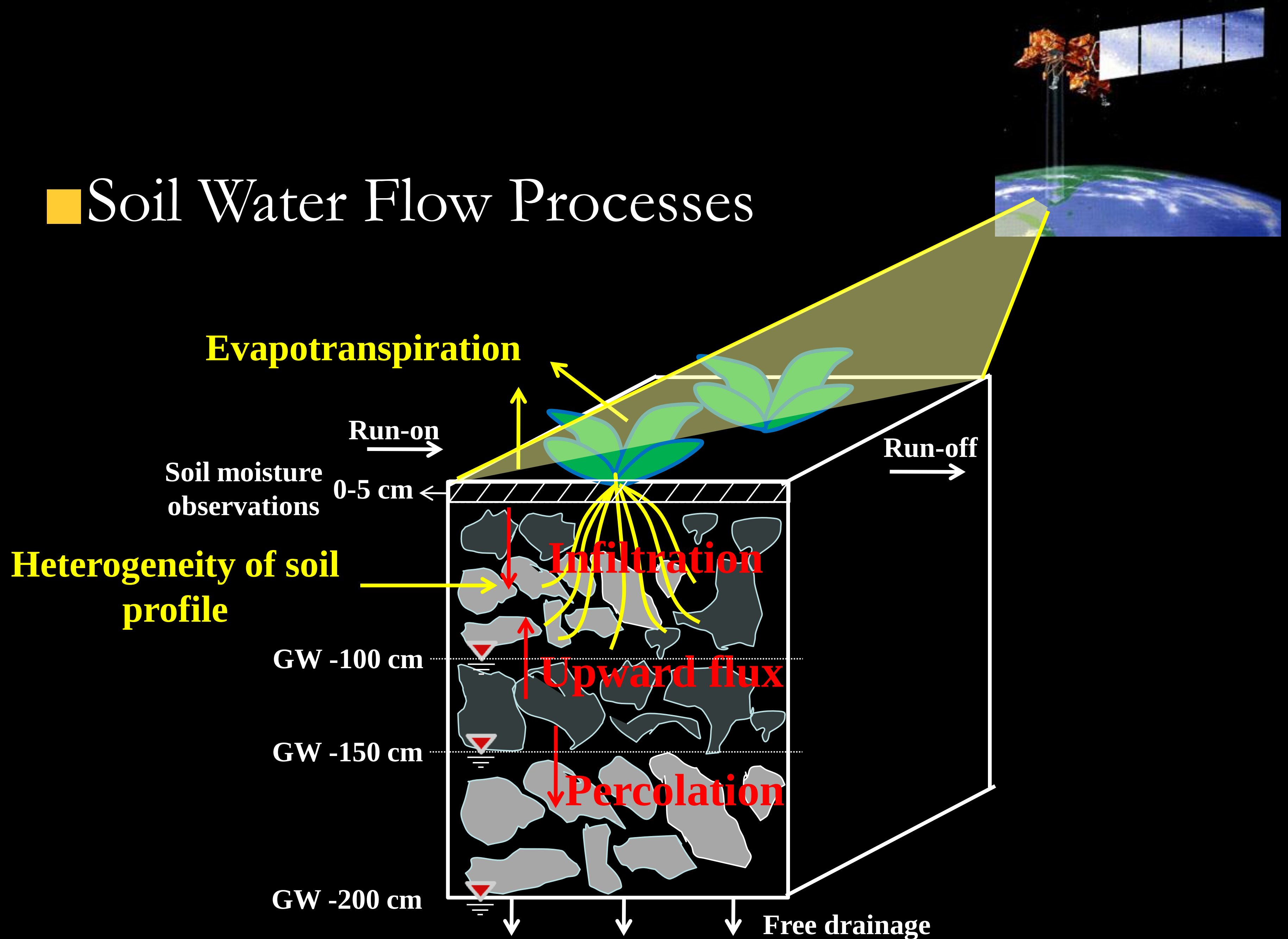
Gopher Holes

Biological Pores


Structural Cracks


Karst Geology

# ■Soil Water Flow Processes



# Soil Moisture at Different Process Scales

**SCALE**

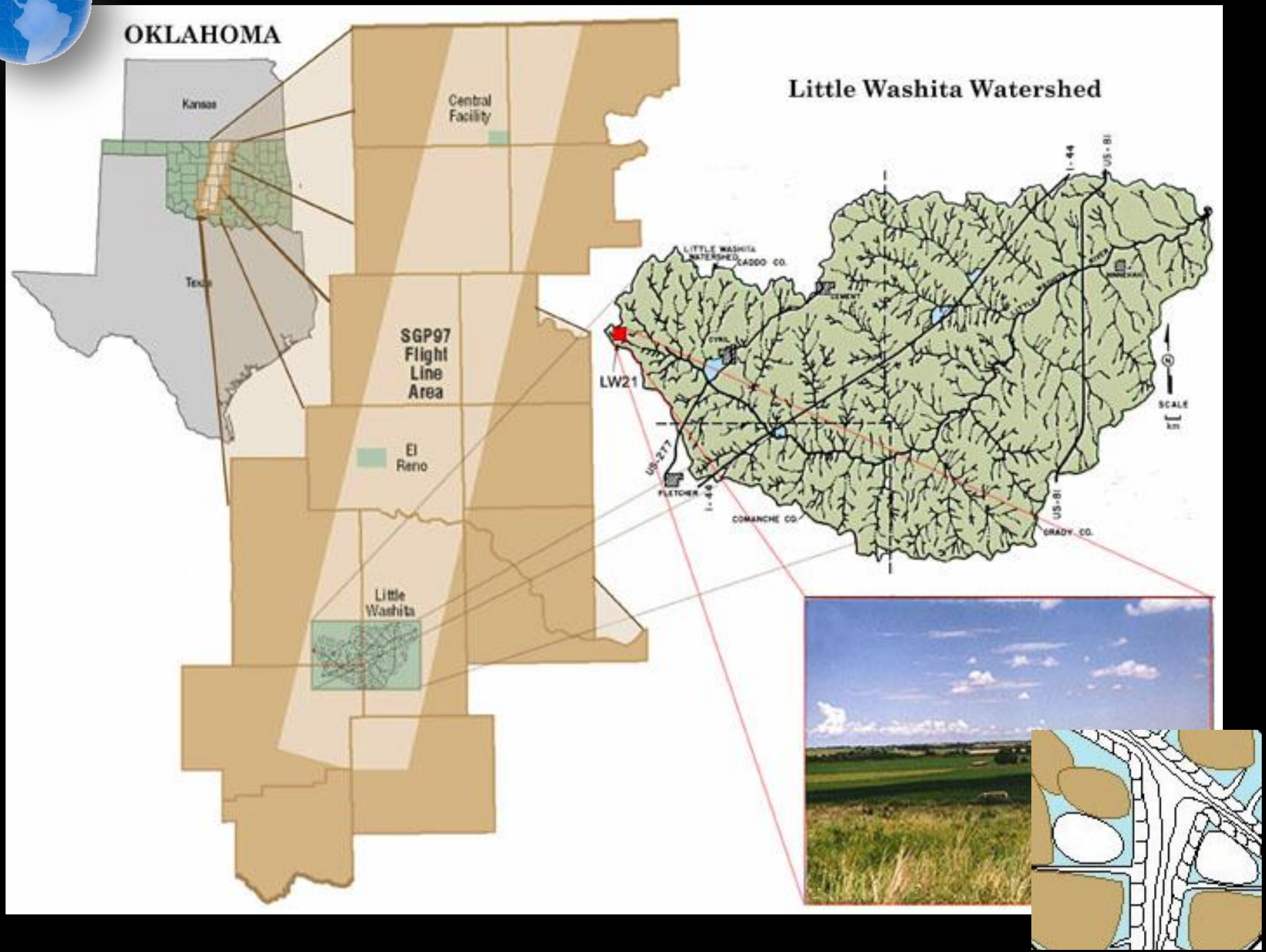
**Global**

**Regional**

**Watershed**

**Field**

**Pore**



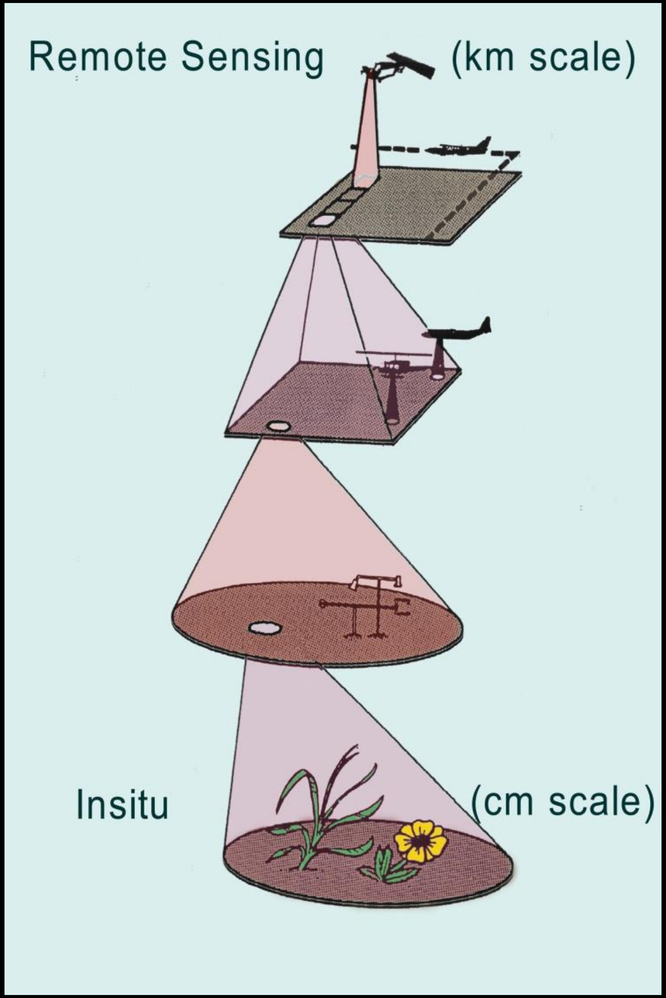
# Soil Moisture / Brightness Temperature Measurement Scales

Space-borne

Air-borne

Ground-based

Insitu




SMOS
SMAP

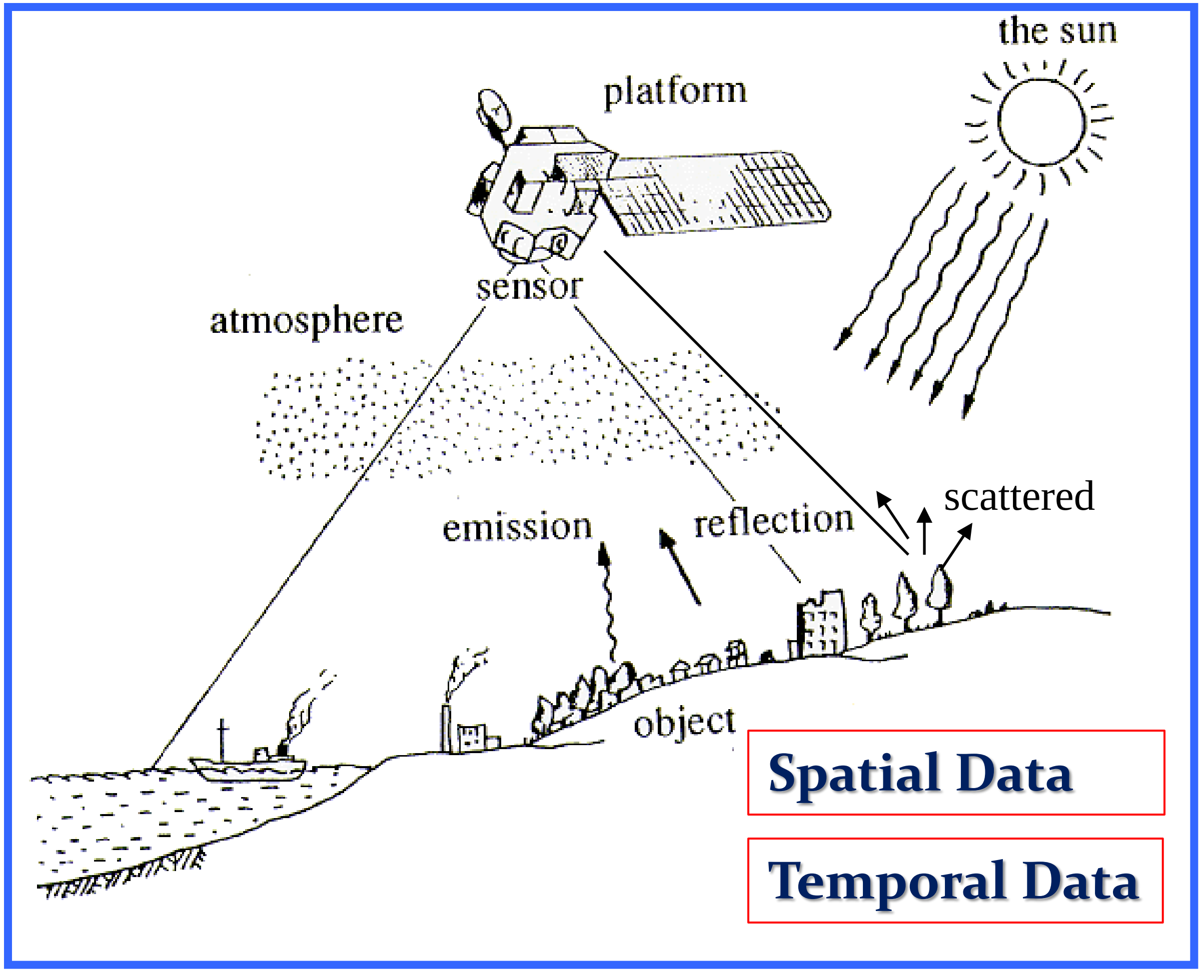
ESTAR
PSR

TOWER
TRUCK

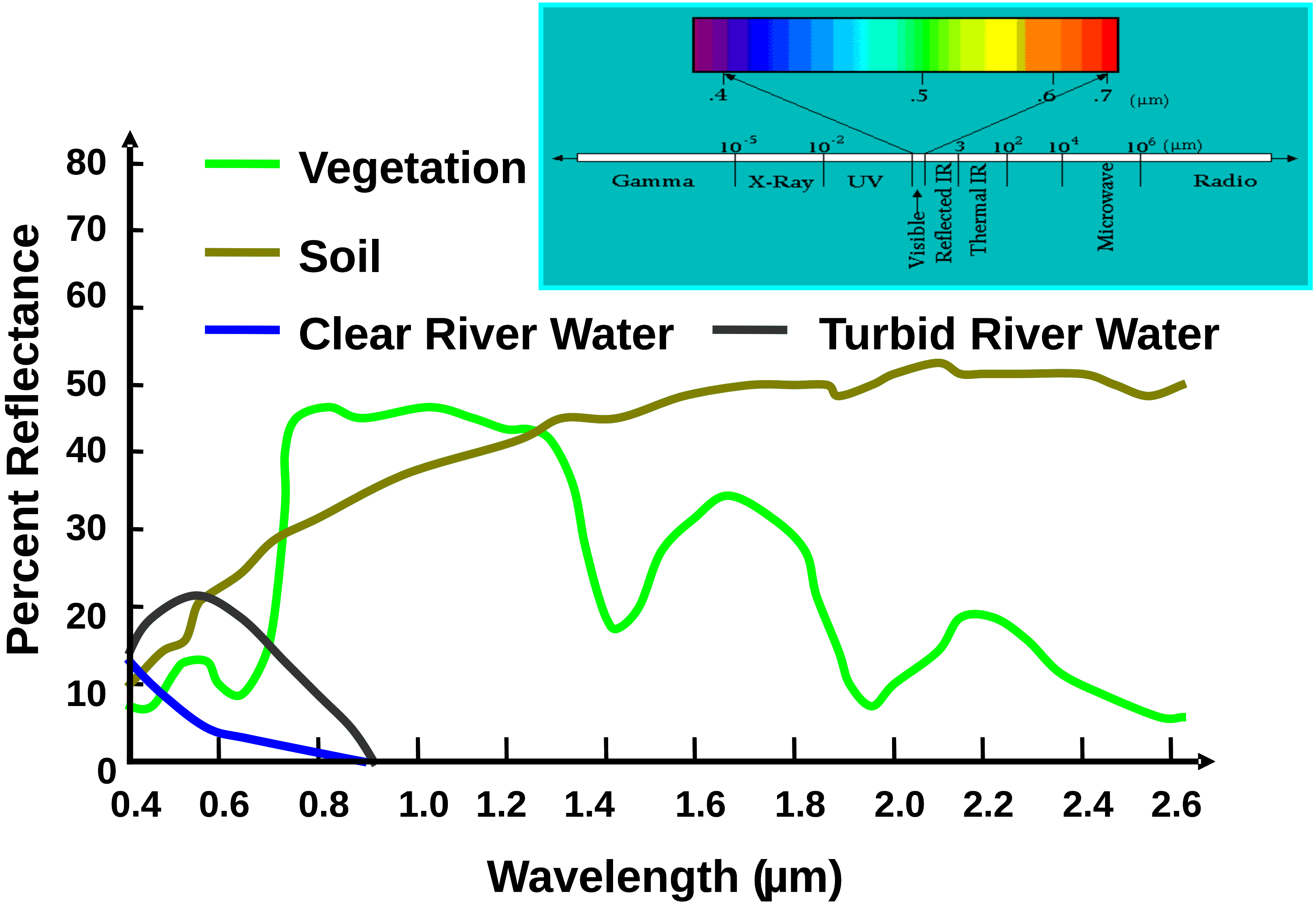
TDR
Gravimetric

**Upcoming Soil Moisture Satellite Missions**
**SMOS, 2010, ESA………SMAP, 2013, NASA**

# Remote Sensing of Environment



# Spectral Reflectance

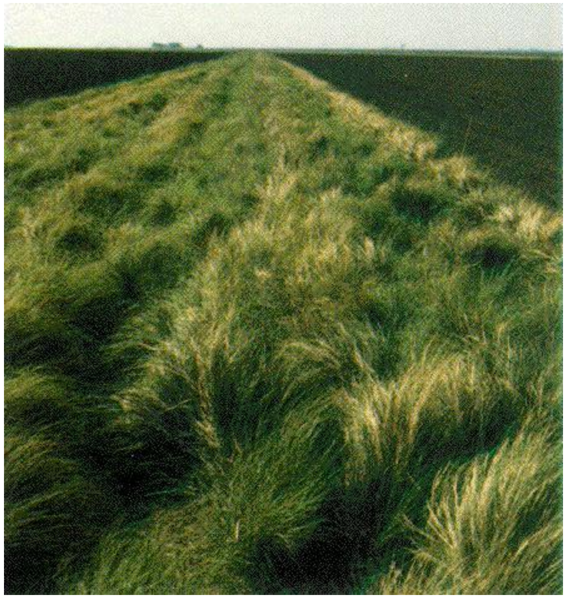


# Remote Sensing of Soil Moisture…

- $T_B$ for **homogenous vegetated surface**:

- $T_B = T_S\{e_s \exp(-\tau_c) + (1-\omega)[1-\exp(-\tau_c)][1+r_s \exp(-\tau_c)]\}$
- $\tau_c = bw_c/\cos\theta$

  - soil and vegetation $T_S$ are assumed to be equal
  - $\tau_c$ vegetation opacity
  - $\omega$ vegetation single scattering albedo
  - b coefficient depends of frequency and vegetation type
  - $w_c$ vegetation water content
  - $\theta$ incidence angle
  - $e_s$ emissivity of soil

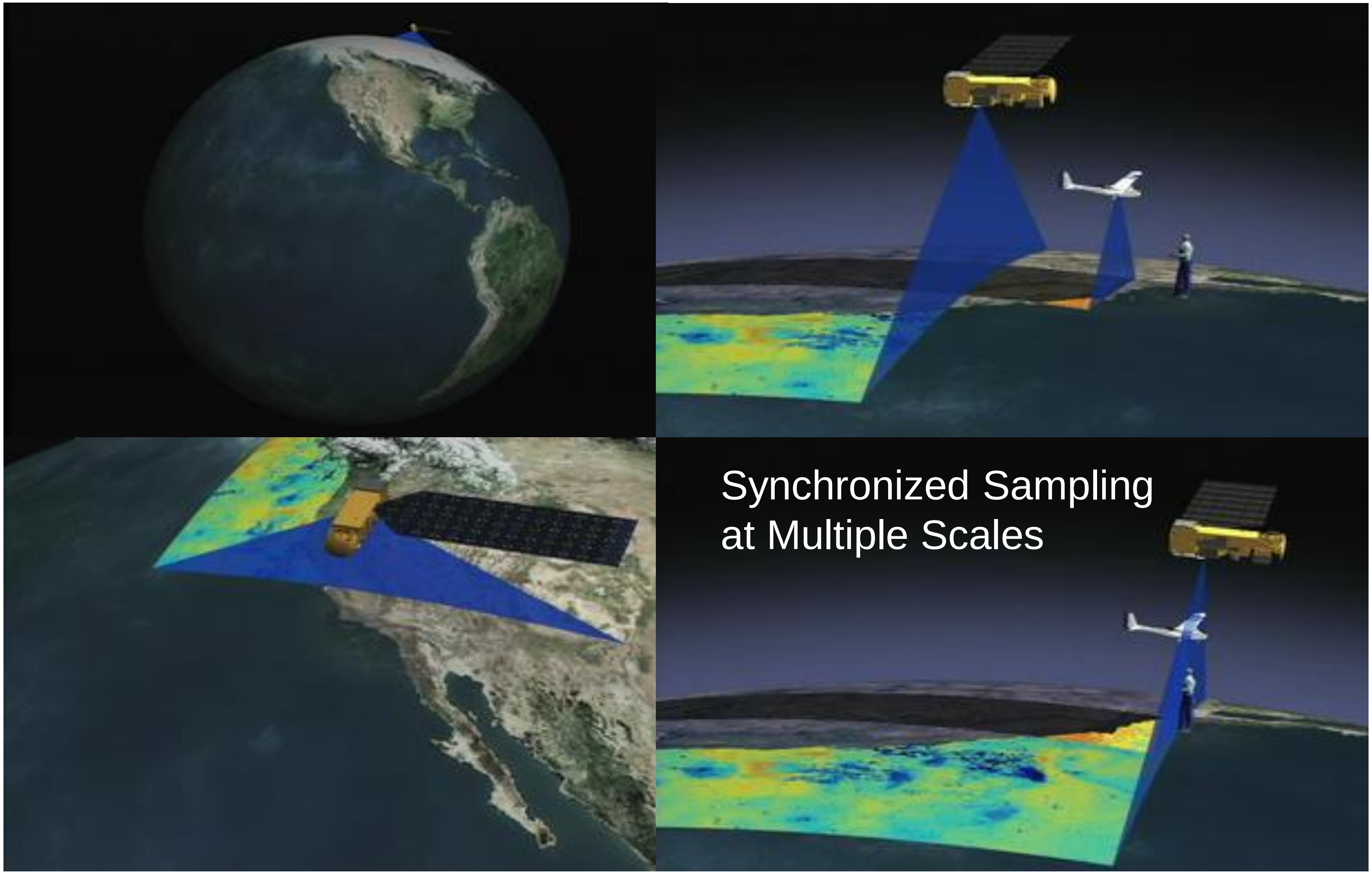


# Remote Sensing of Soil Moisture…

- Reflectivity of a **rough soil surface**:

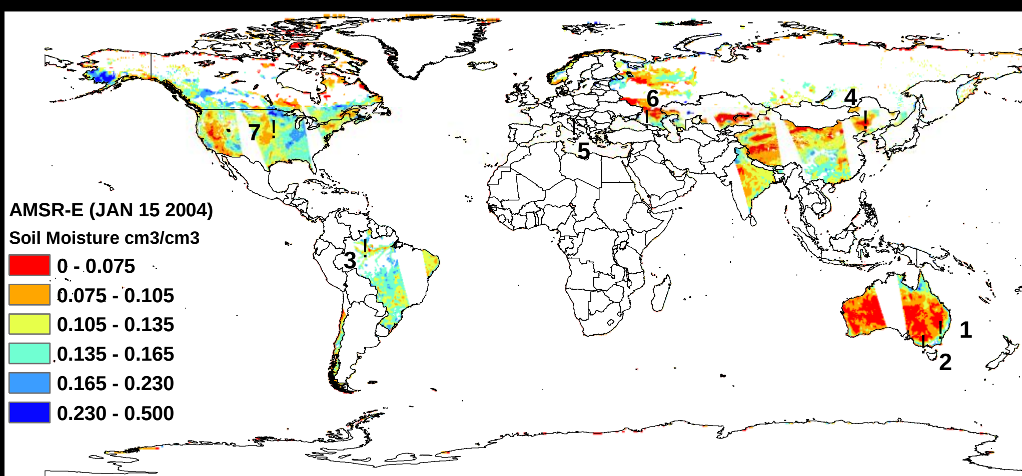
- $r_s=[(1-Q)r_o + Qr_o)] \exp(-h)$
    - Q,h are roughness parameter
    - $r_o$ reflectivity of a smooth surface

# Remote Sensing Cal/Val Studies for Soil Moisture



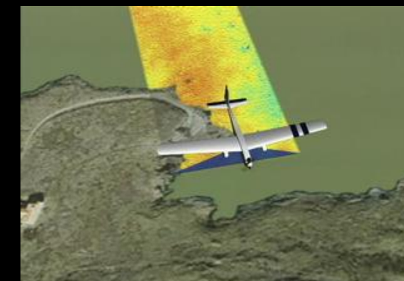
# Soil Moisture Remote Sensing

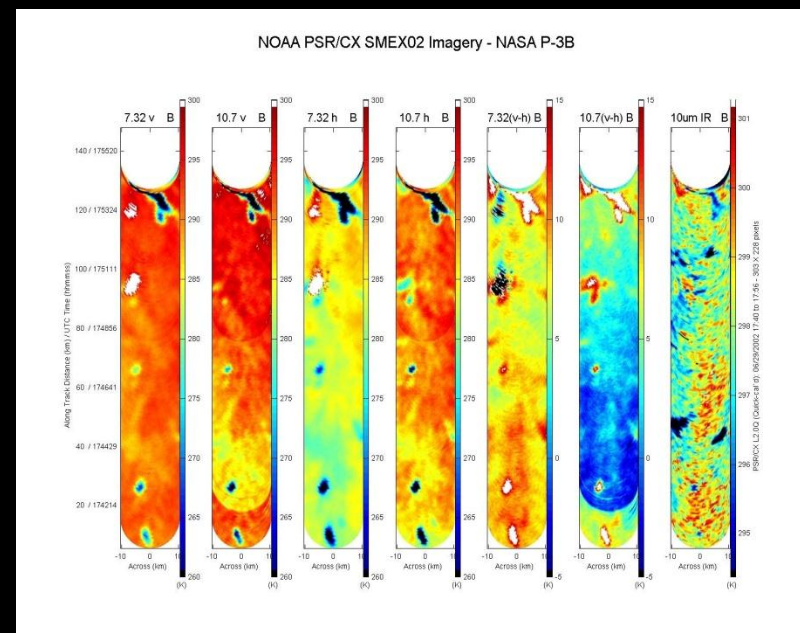
Space-Borne
NASA: AMSR-E on AQUA




Global Coverage every 1.5 days

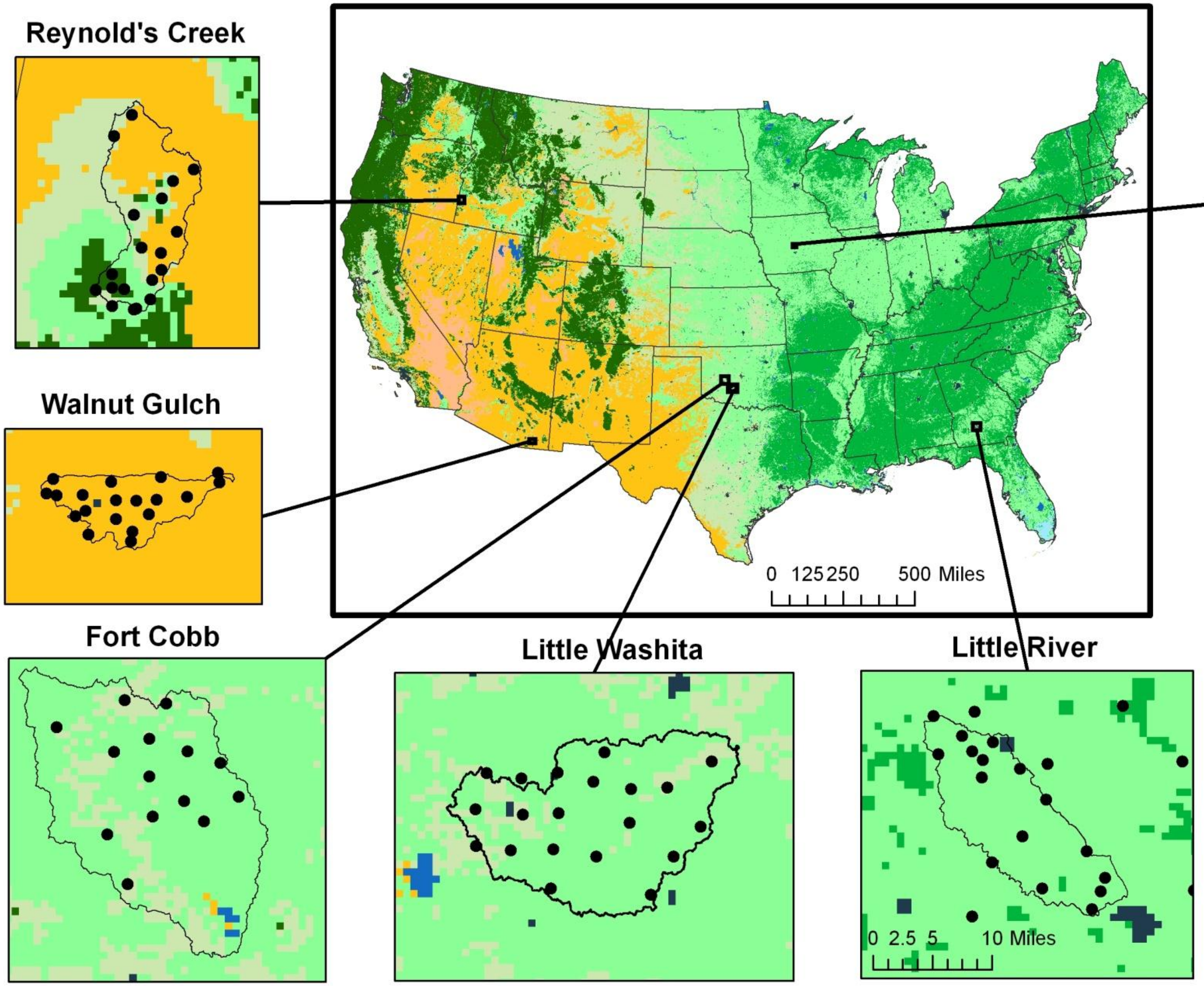
Air-Borne
NOAA: PSR






Spatio-Temporal Data in Iowa

# U.S. Watershed Soil Moisture Validation Sites





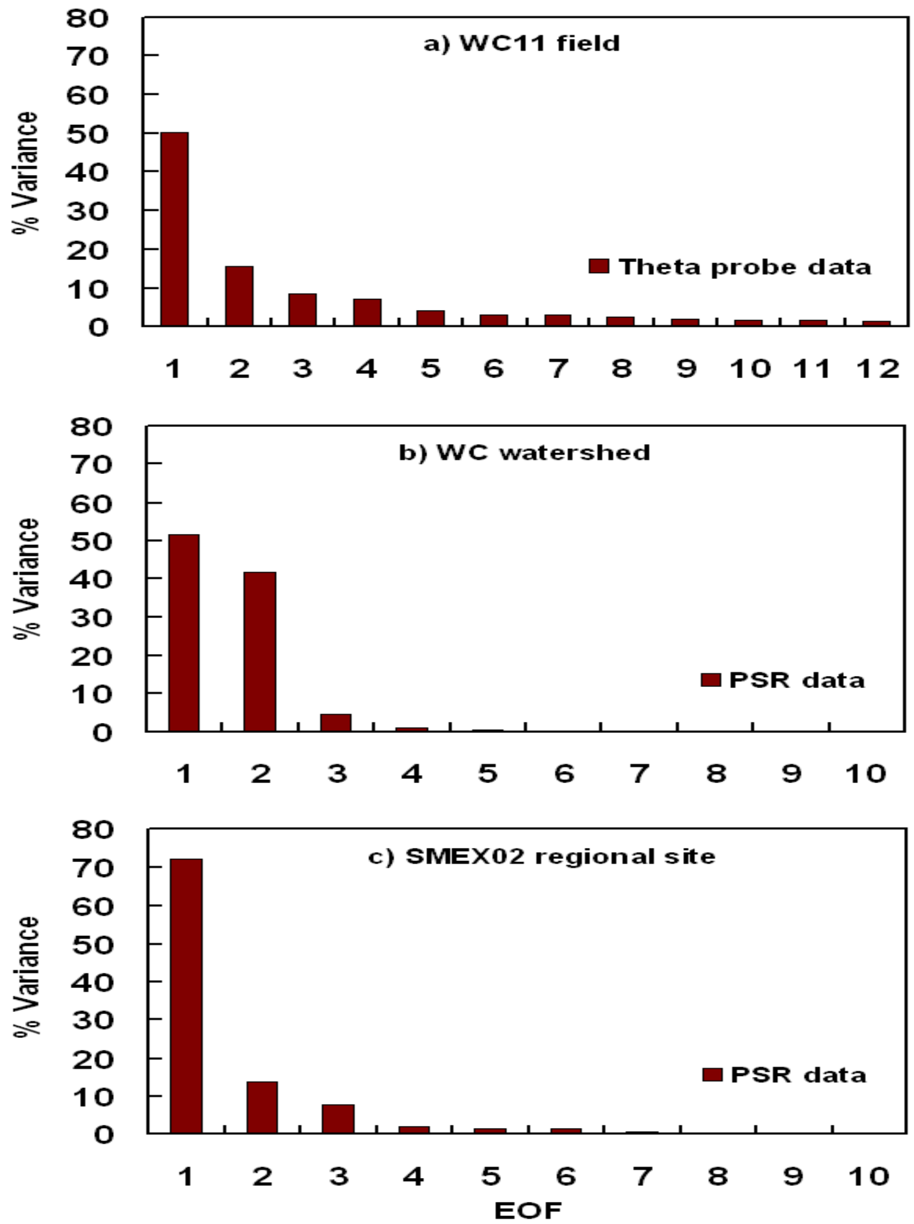
- All sites include 5 cm
- LW, LR, WG, RC since 2002
- WC, FC are new

# EOF Analyses Across Scales in Iowa During SMEX02

**Field-scale**

**Watershed-scale**

**Regional-scale**

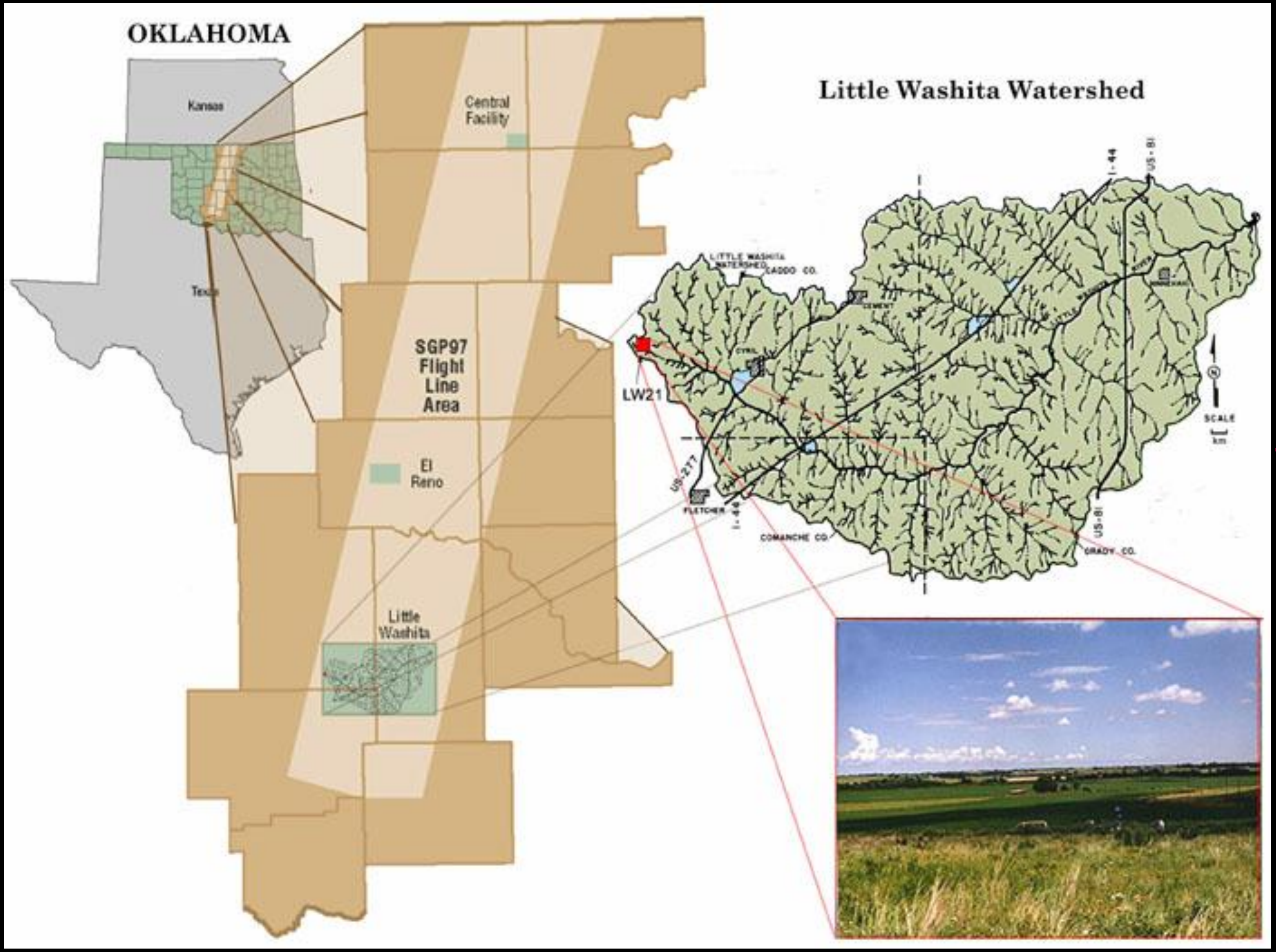


# Soil Moisture Dominant Physical Controls at Different Spatial Scales

Region

Watershed

Field



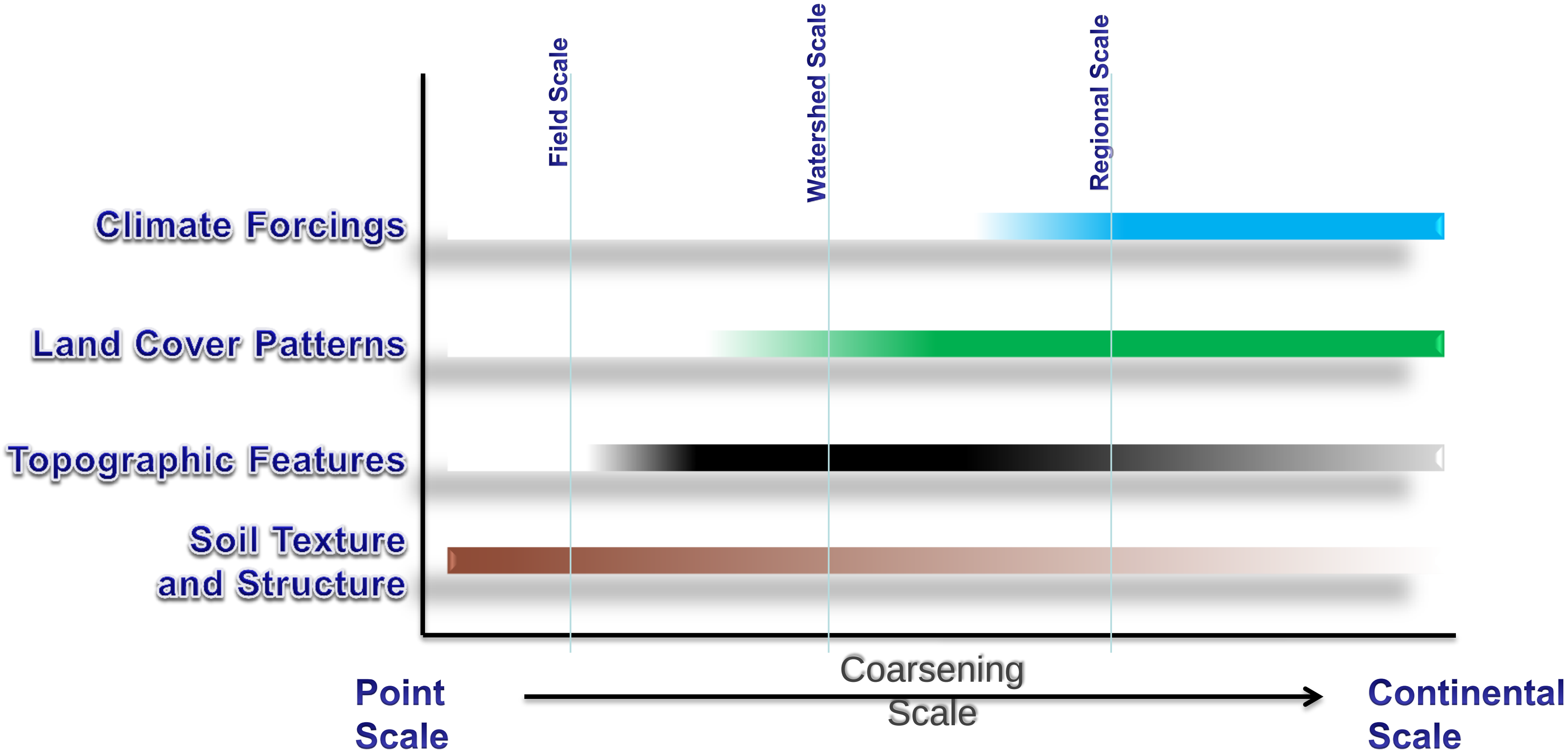

Vegetation/ Precipitation

Topography

Soil

# Hypothesis

- Soil moisture variability is dominated by



# Modeling Soil Moisture

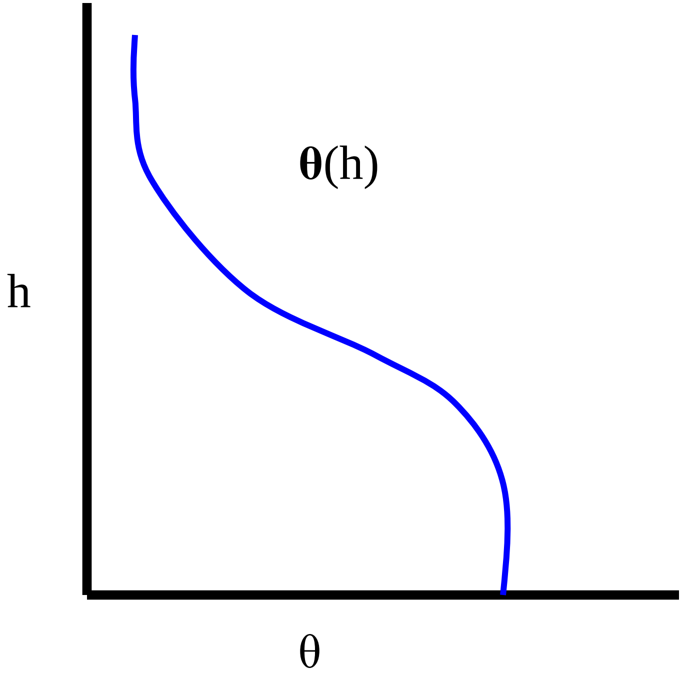
- Importance of modeling – **RS of soil moisture only limited to near-surface soil layers**
- 1D Flow equation: (Assumption: work at any scale!!)

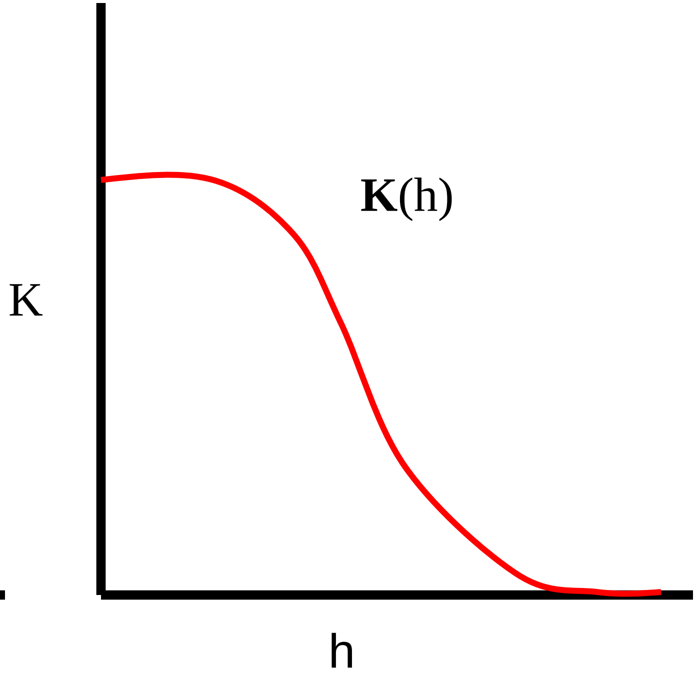
$$\frac{\partial \theta(h)}{\partial t} = C(h)\frac{\partial h}{\partial t} = \frac{\partial\left[K(h)\left(\frac{\partial h}{\partial z}+1\right)\right]}{\partial z} - S(h)$$

$$S(h) = \alpha_w(h)\frac{T_{pot}}{|z_r|}$$

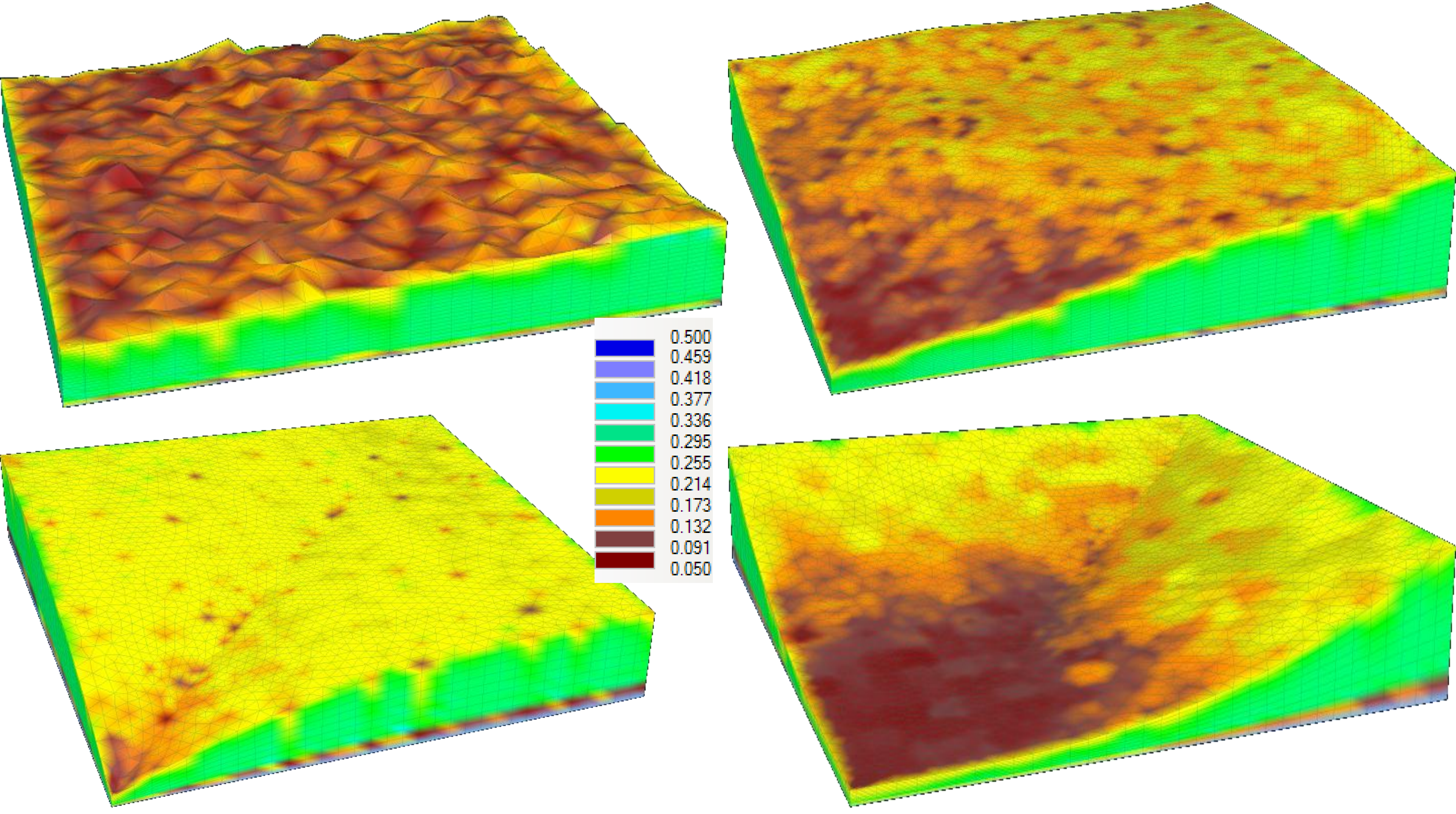
# Soil Hydraulic Properties

- Soil-moisture retention property, **θ**(h)
- Soil hydraulic conductivity property, **K**(h)

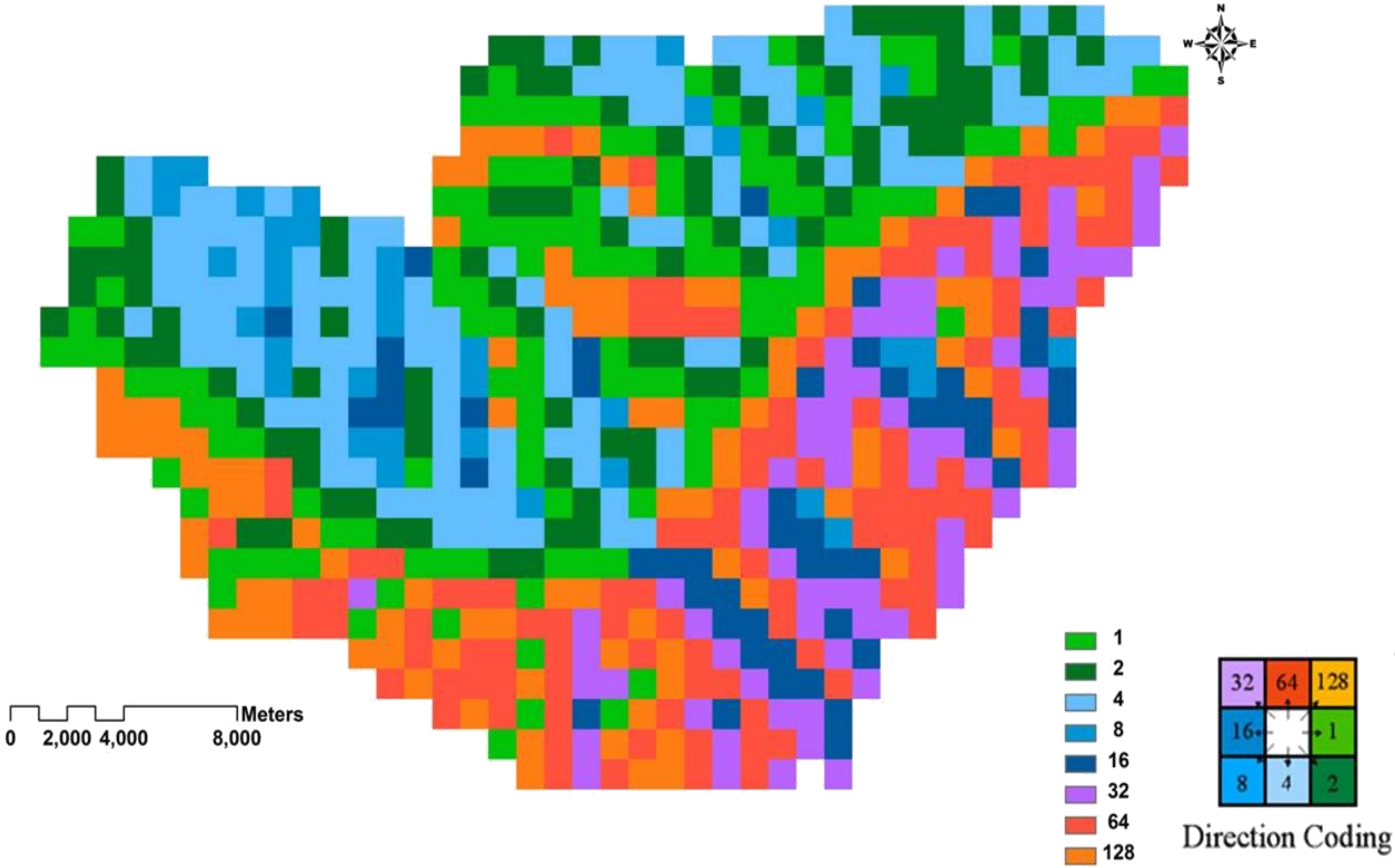


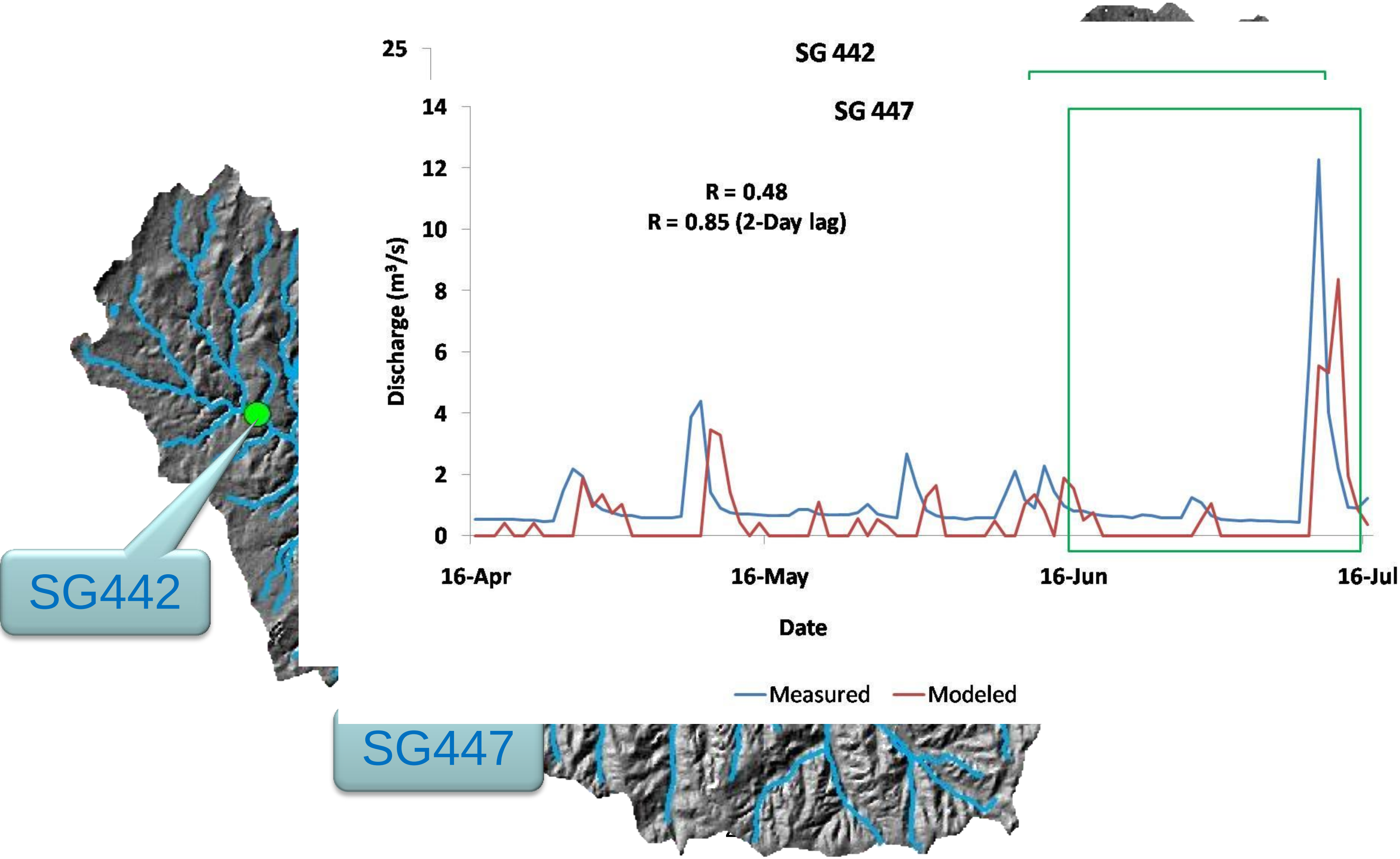
# Modeled Soil Moisture States under Different Topographic Configurations



# Flow Routing at Watershed Scale



# Stream Flow Comparison



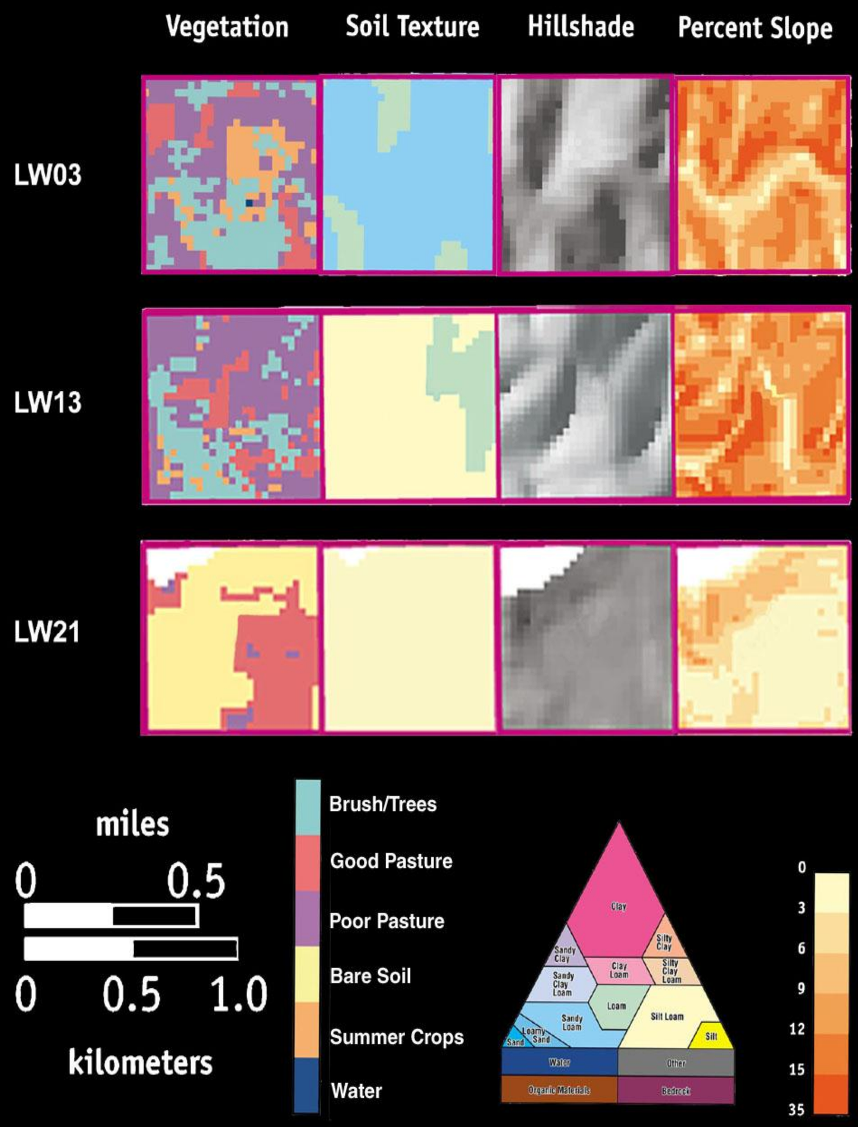
# Motivation

- To address the connections between the environmental factors and "effective" soil hydraulic parameters at various scales across the land surface

- To develop scaling (downscaling and upscaling) algorithms, data assimilation, inverse model, and incorporation of stochastic evolutionary schemes

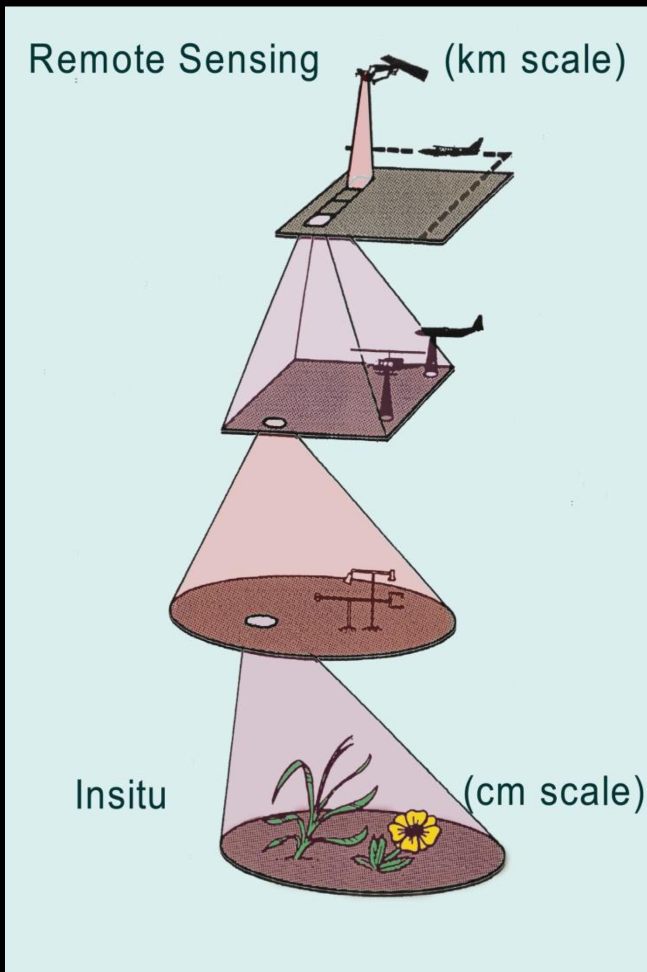
# Limitation: What is Pixel-Scale Parameter!?

Vegetation Soil Slope



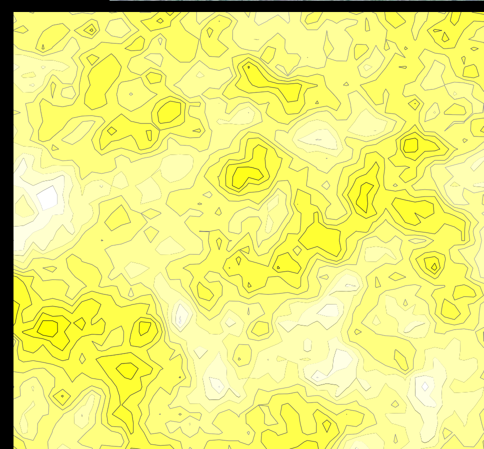
# Top-down versus Bottom-up Approach

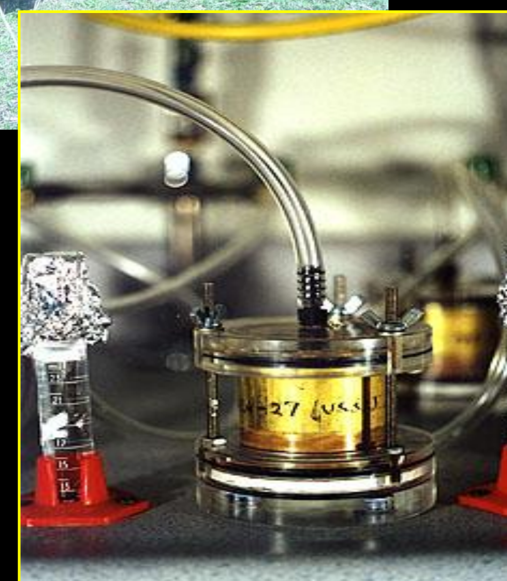
## New Study




**Hydraulic Property Estimation**
**Across the Pixel :**
**Top- Down Approach**

## Traditional Soil Physics





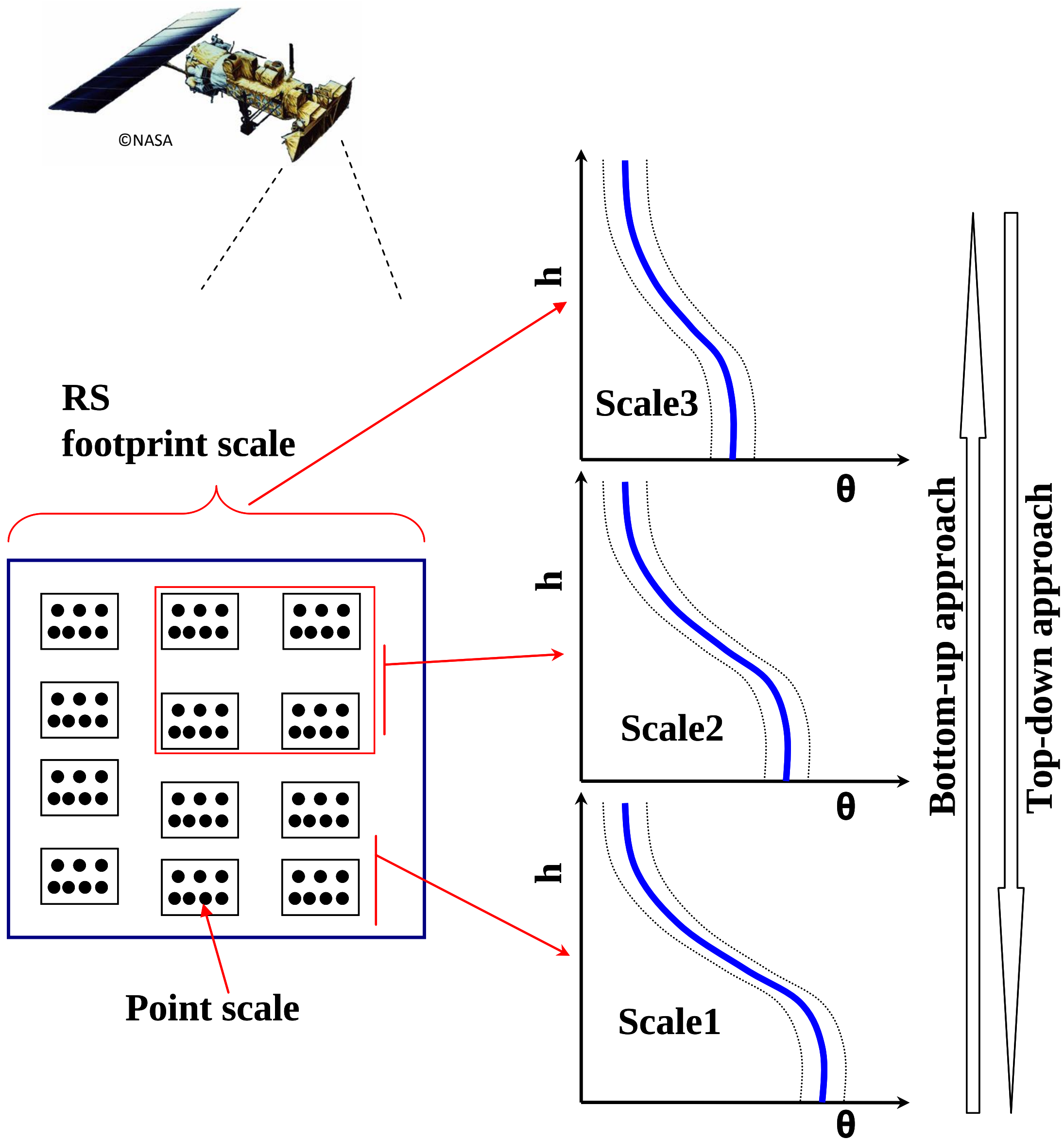
**Hydraulic Property Measurement**
**Across the Pixel :**
**Bottom- Up Approach**

# Soil Hydraulic Function Scaling Hypothesis

**Using the information content of the soil moisture data collected at that particular SCALE, we can <u>estimate</u> the scale dependent soil hydraulic properties**

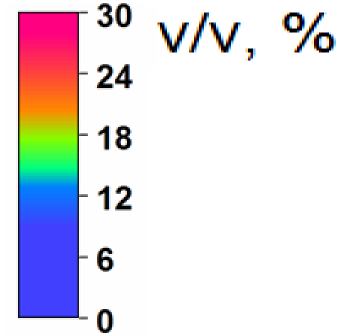
$$S_e = \frac{\theta(h)-\theta_{res}}{\theta_{sat}-\theta_{res}} = \left[\frac{1}{1+|\alpha h|^n}\right]^m$$

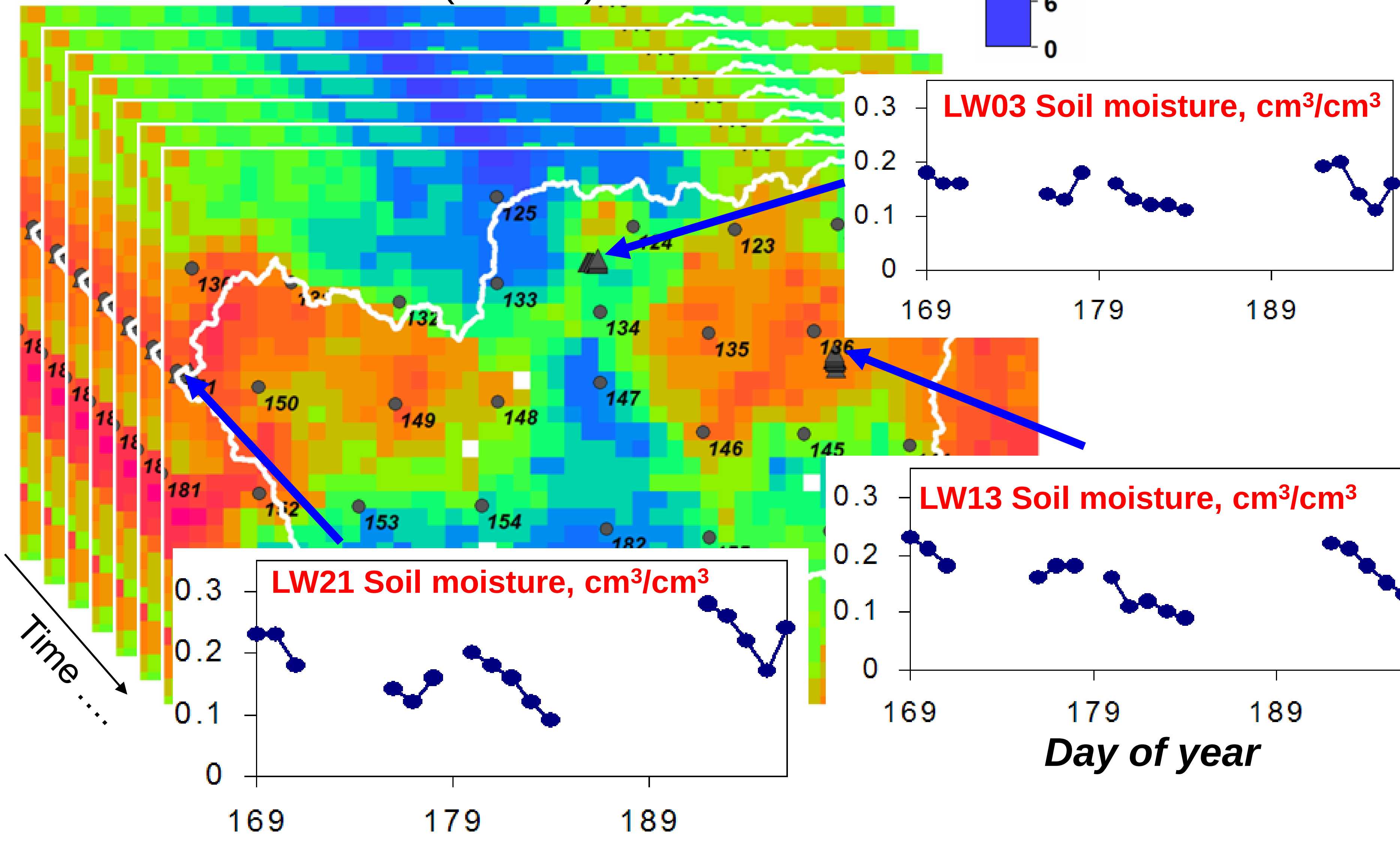
$$K(h)=K_{sat}S_e^{\lambda}\left[1-\left(1-S_e^{1/m}\right)^m\right]^2$$



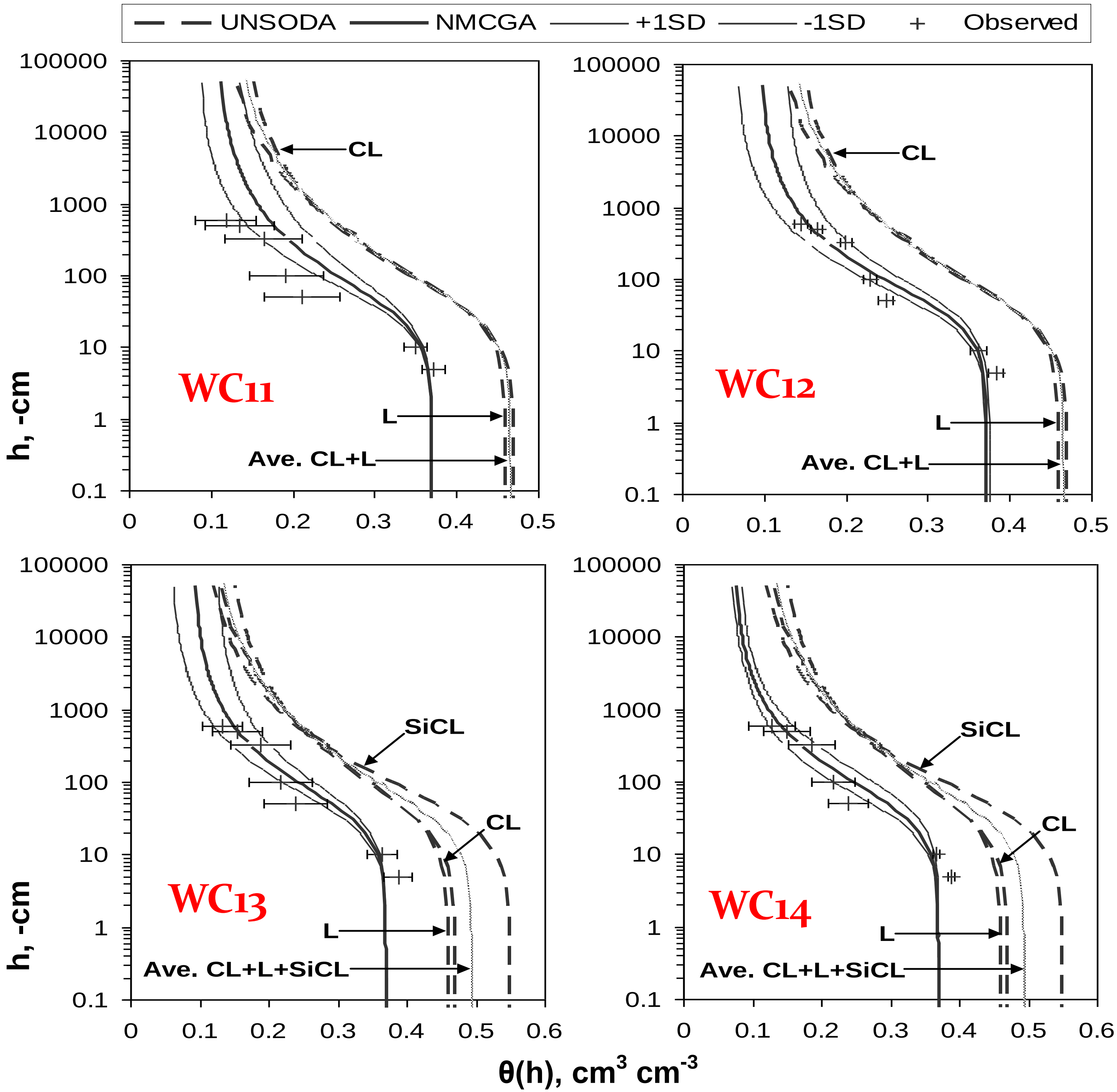
# Remote sensing data

- Airborne: **ESTAR** (SGP97)

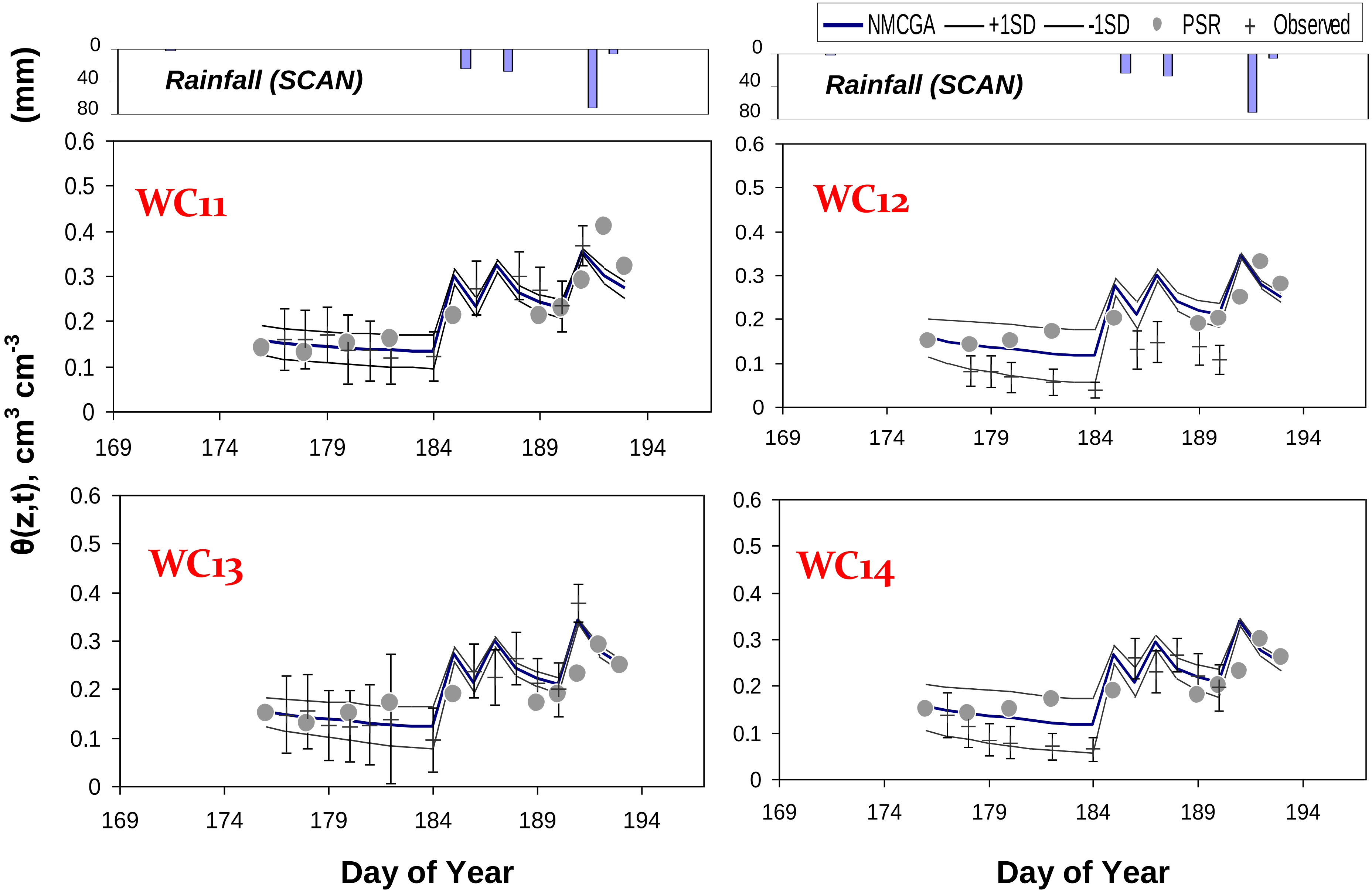


# Air-borne RS scale (Polarimetric Scanning Radiometer: PSR)



# Simulated vs. Observed Soil moisture



# Objectives

- To explore the scale dependency for certain soil hydraulic parameters used in LSMs:

  saturated hydraulic conductivity, residual and saturation soil water contents, and van Genuchten parameters

- To develop suitable mathematical approaches for downscaling and upscaling hydarulic parameters in complex terrains. This proposed approaches would honor both vertical and horizontal fluxes

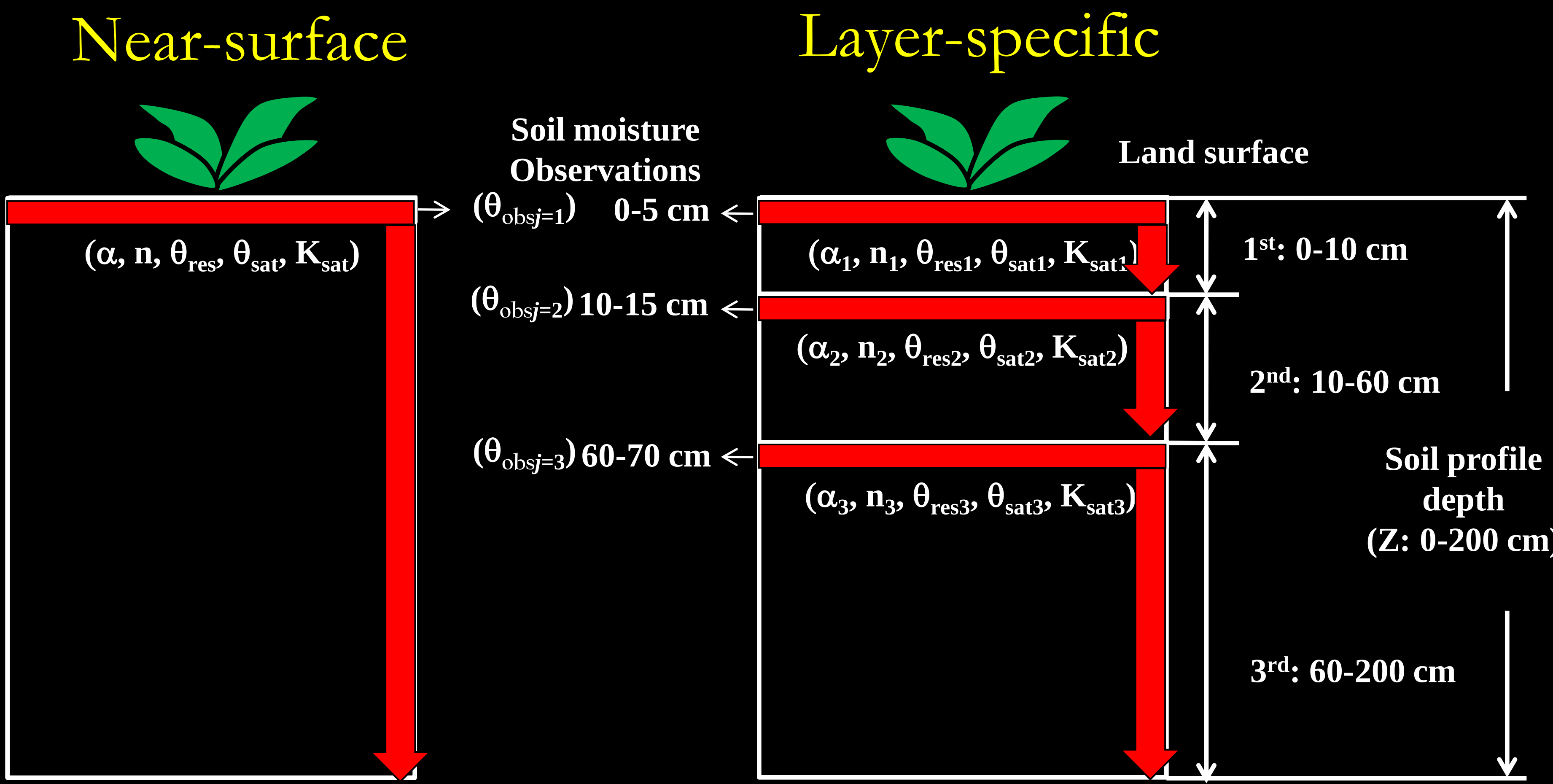
# Research Approach

- Near-surface soil moisture assimilation scheme based on inverse model

- Physically-based (Richard's equation) hydrological models (Soil Water Atmosphere Plant-SWAP, Community Land Model-CLM, and Noah land surface model-Noah LSM)

  - SWAP: Mualem-van Genuchten (MVG) parameters
  - CLM: Clapp and Hornberger empirical equation
  - Noah LSM: Clapp and Hornberger empirical equation

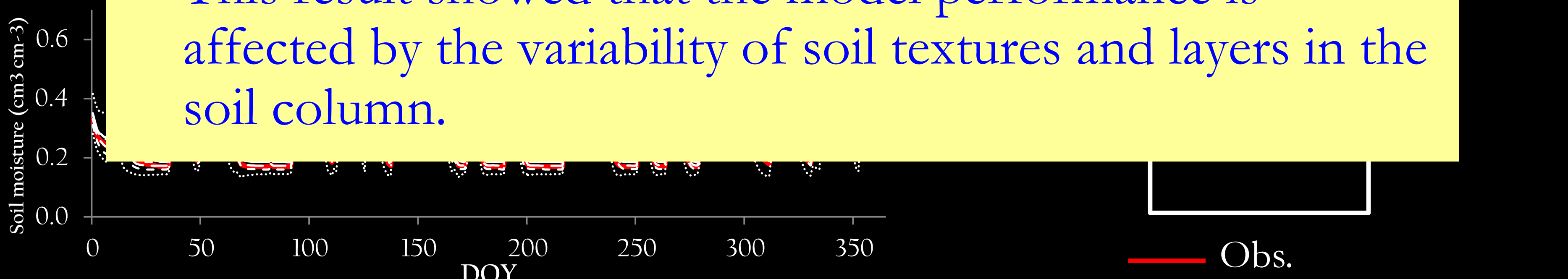
# Comparison of Layer-Specific and Near-Surface Assimilation approaches

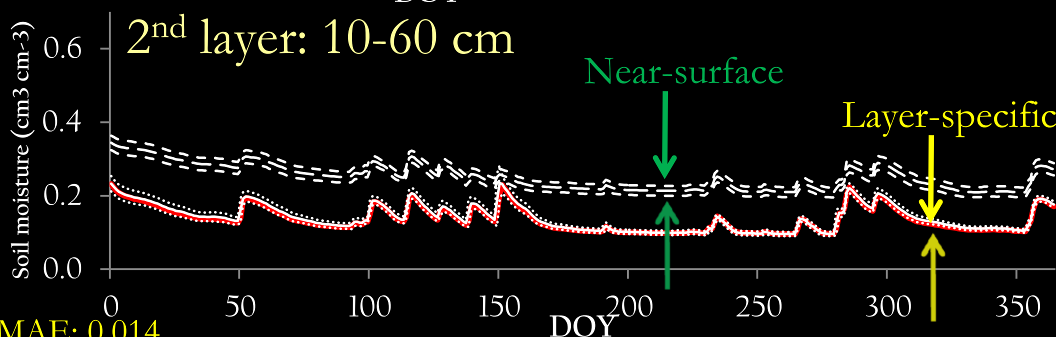


# Results

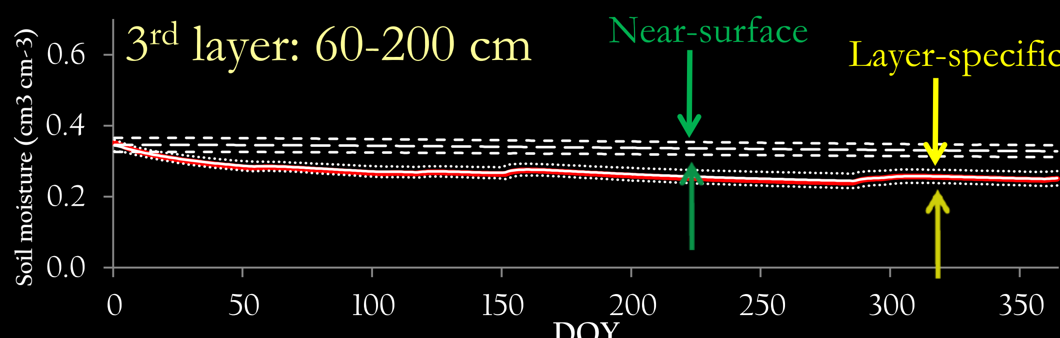
- Case 1: Comparison of layer-specific/near-surface approach

This result showed that the model performance is affected by the variability of soil textures and layers in the soil column.

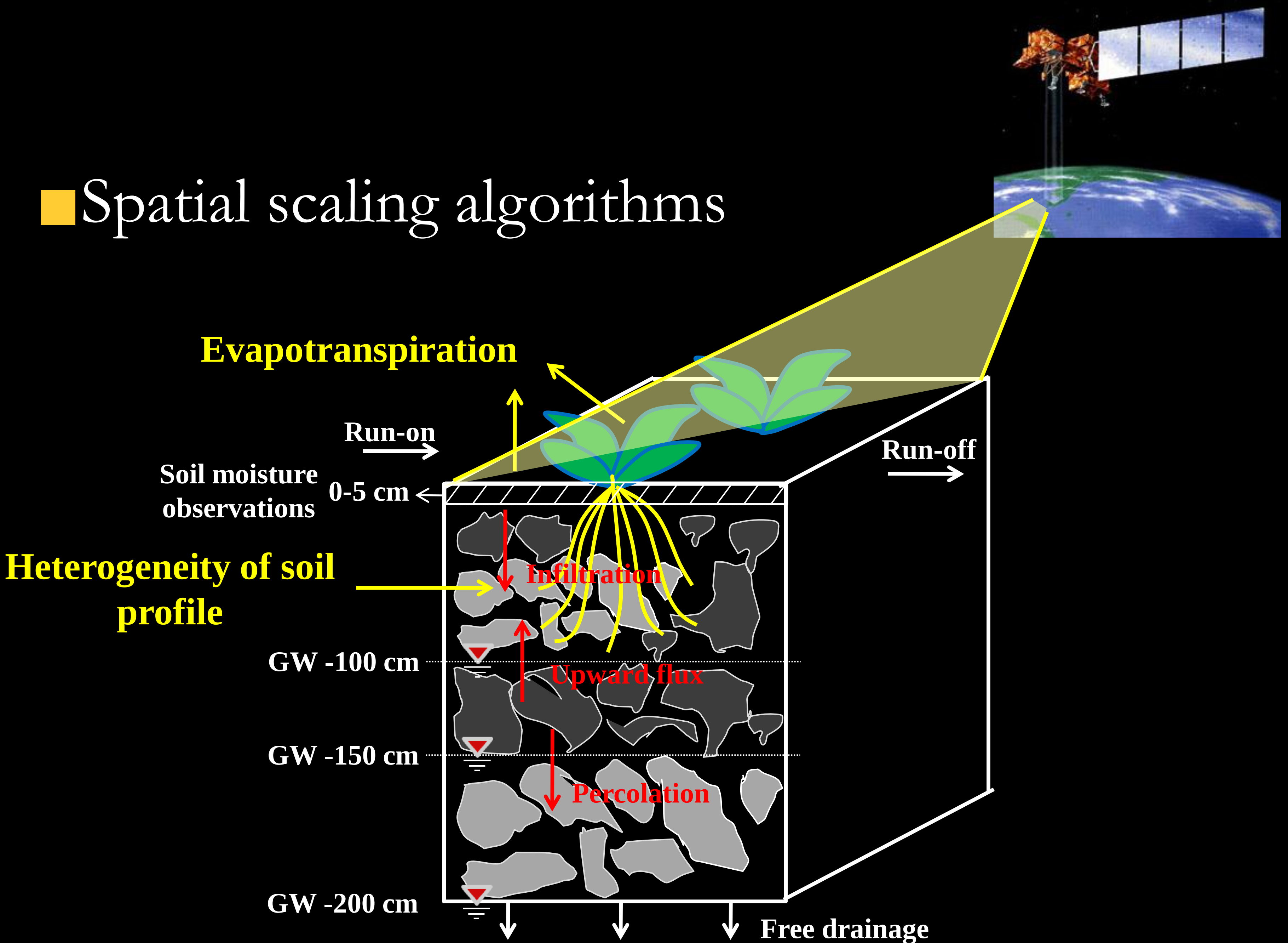


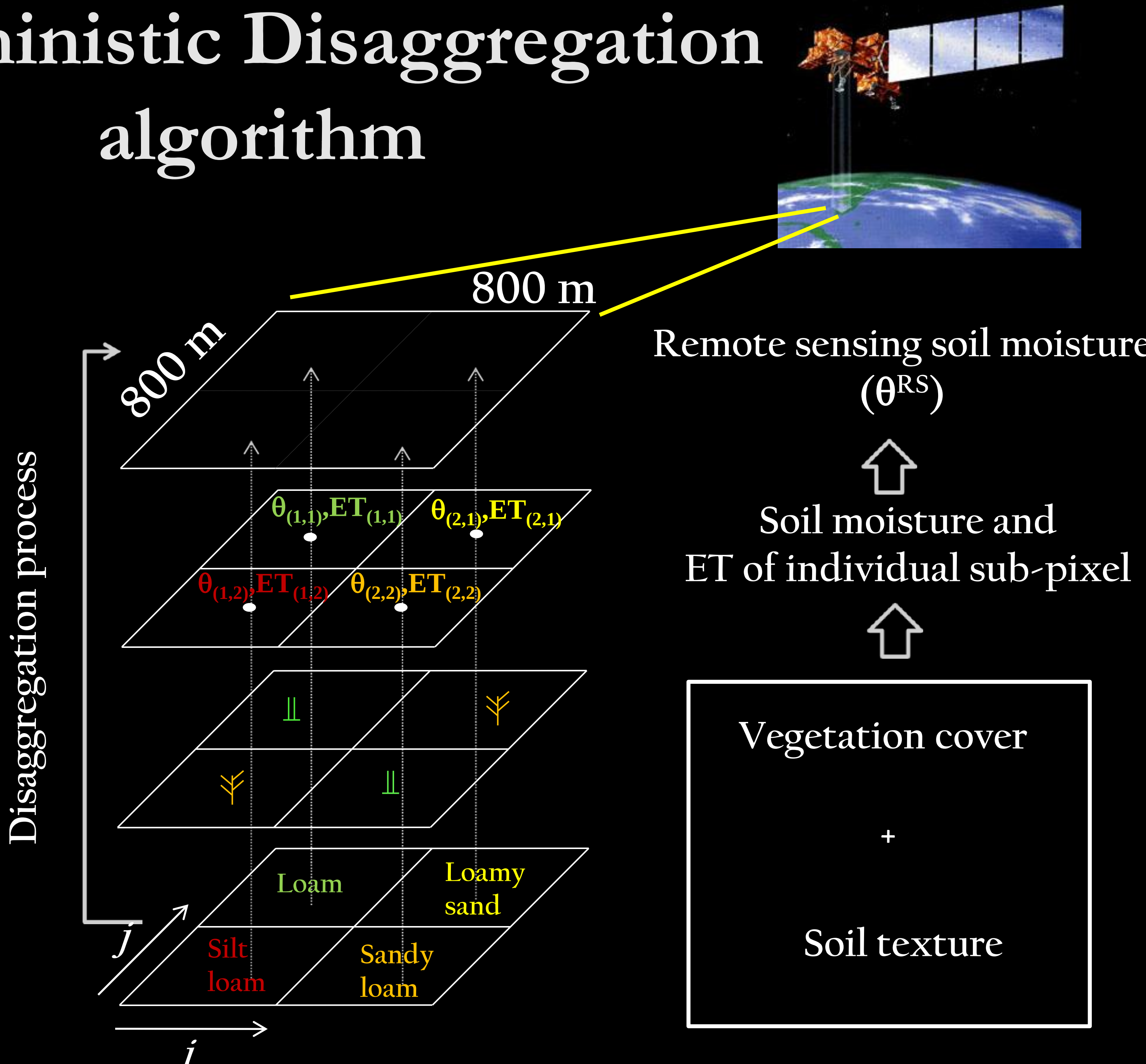

1st layer
$R^2$: 0.997, MAE: 0.014
$R^2$: 0.981, MAE: 0.013
2nd layer
$R^2$: 0.995, MAE: 0.004
$R^2$: 0.832, MAE: 0.114
3rd layer
$R^2$: 0.998, MAE: 0.003
$R^2$: 0.786, MAE: 0.072



# ■Spatial scaling algorithms

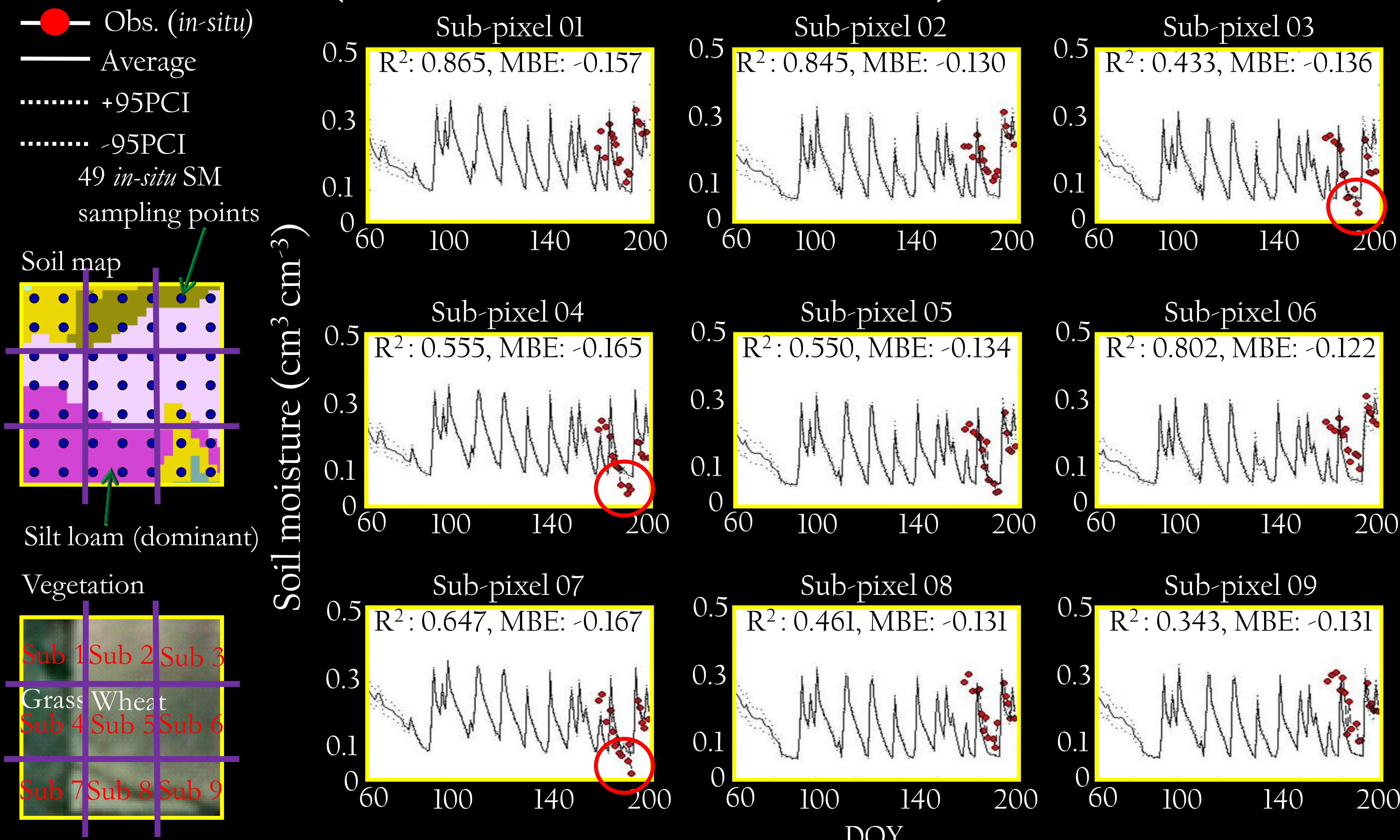


# Deterministic Disaggregation algorithm



# Results - Soil Moisture

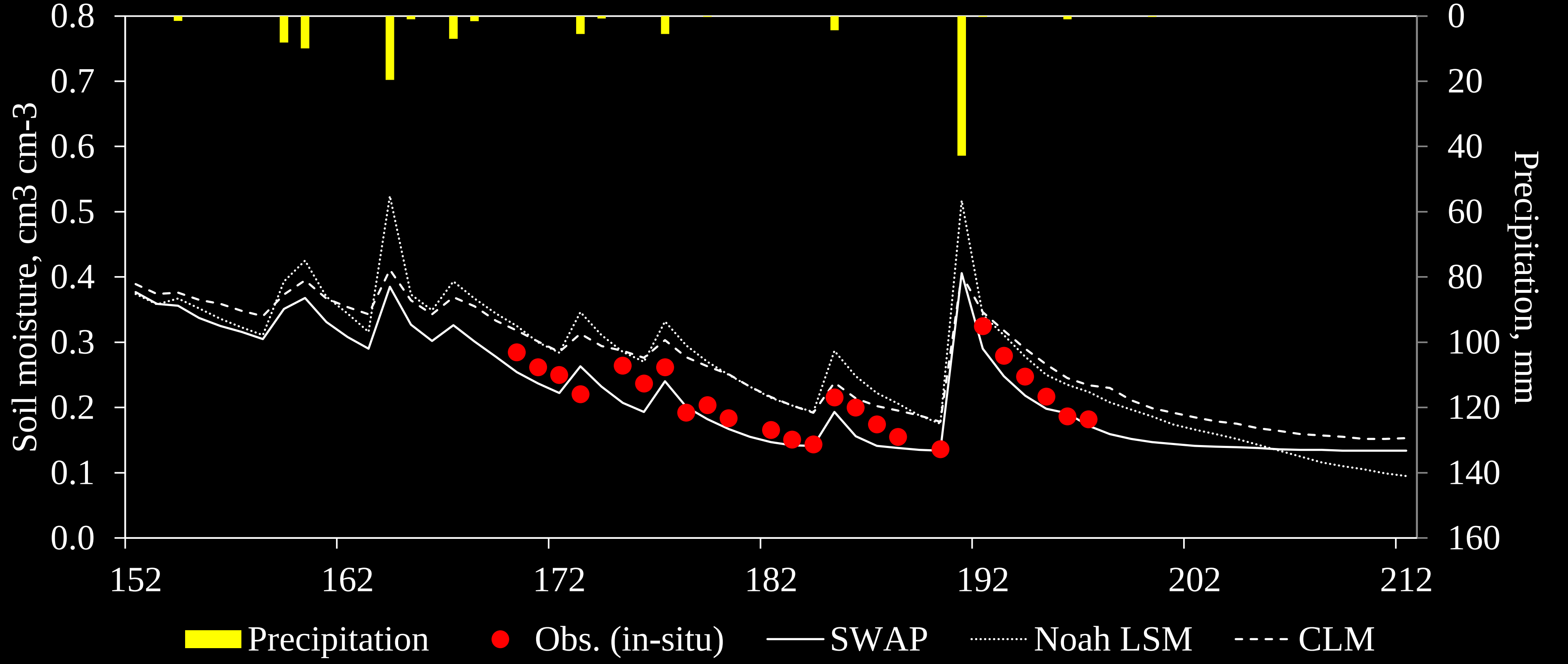
- LW 21 site (ESTAR, 800 m × 800 m)



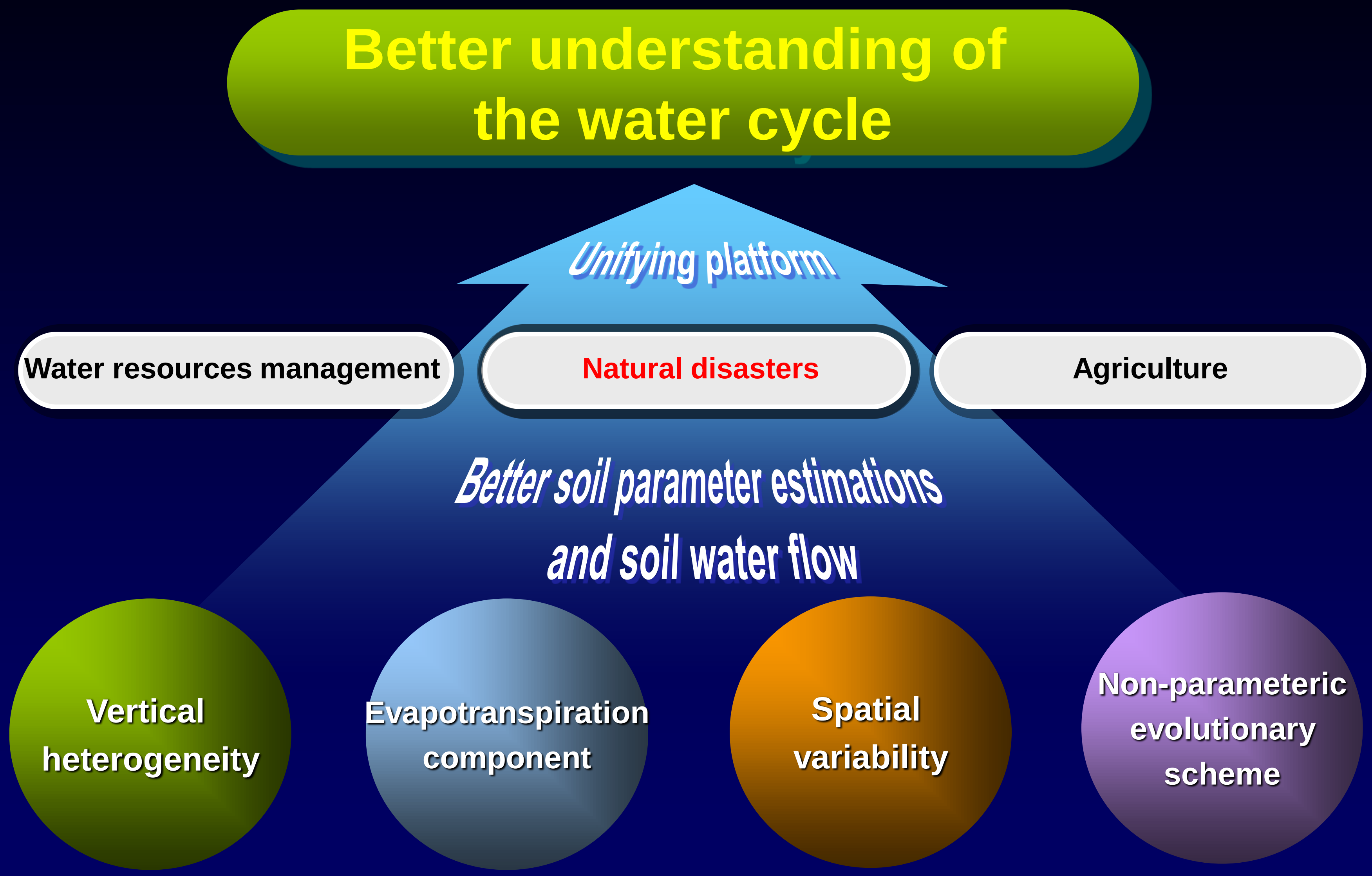
# Results

- Comparison of *in-situ* and average (for the upscaled sub-pixels) soil moisture dynamics for SWAP, CLM, and Noah LSM.

**SWAP-$R^2$: 0.913, RMSE: 0.029 Noah LSM-$R^2$: 0.877, RMSE: 0.058 CLM-$R^2$: 0.927, RMSE: 0.051**




**In order to support the robustness of our approach, we tested various hydrological models in the upscaling process only.**



Better understanding of
the water cycle
Unifying platform
Water resources management
Natural disasters
Agriculture
Better soil parameter estimations
and soil water flow
Vertical
heterogeneity
Evapotranspiration
component
Spatial
variability
Non-parameteric
evolutionary
scheme

# Increasing Drought Severity

- Drought is one of the most severe environmental outcomes of the climate change
- Texas suffered under an intense drought driven by La Niña with a total damage of $ 7.6 billion
- Drought severity assessment using precipitation data
- Agricultural drought influenced by not only weather conditions, but also by root zone soil moisture
- No study of finer-scale drought severity evaluations using remotely sensed soil moisture

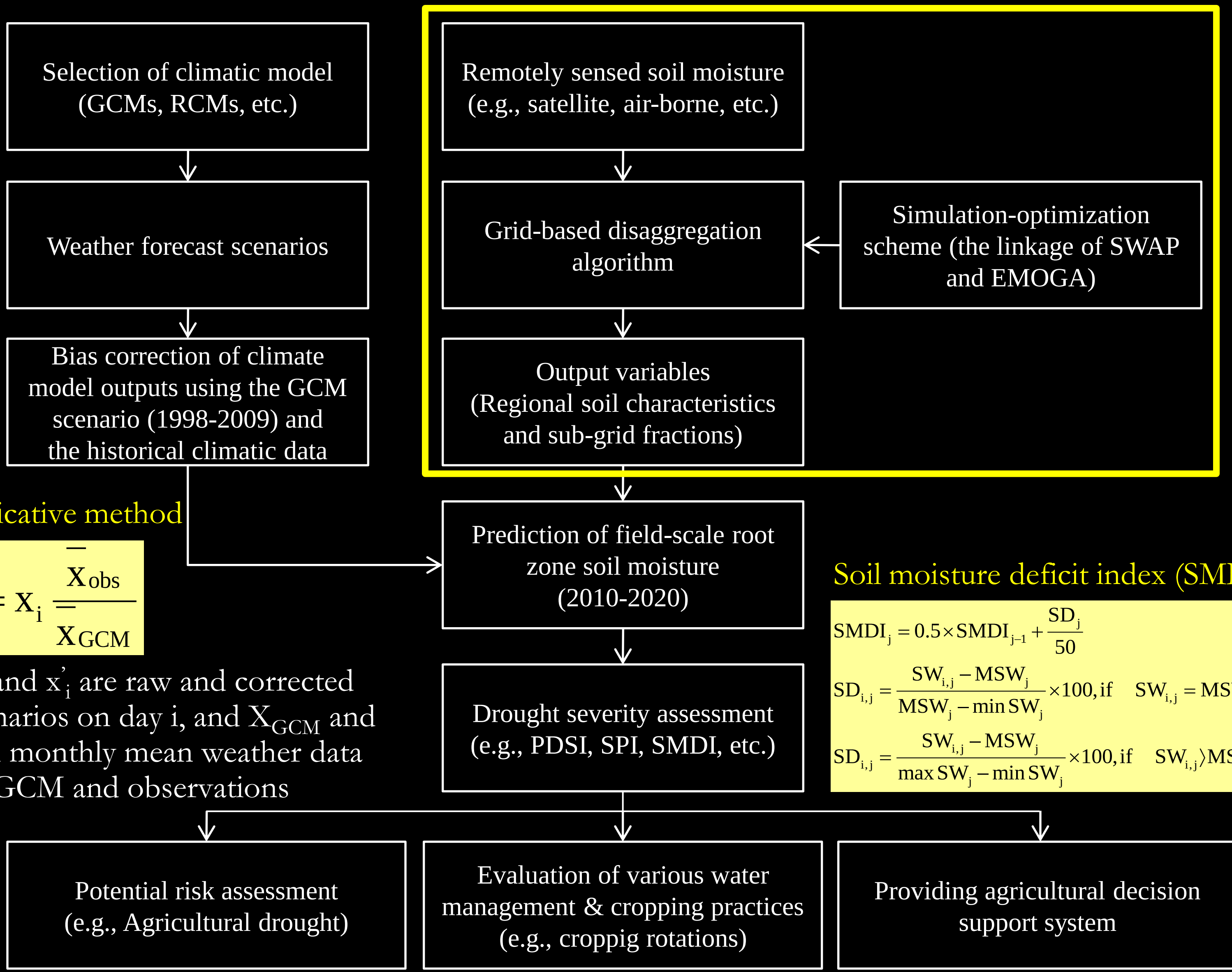
- To develop a drought severity assessment framework using remotely sensed soil moisture products

  - Global circulation model (GCM) based climate forecasts

- To evaluate the finer-scale drought severity under various environmental factors

  - Various soil textures, vegetations, soil depths, shallow ground water tables, etc.

# Agricultural Drought Severity Platform




Multiplicative method

$$x_i' = x_i \frac{\overline{X}_{obs}}{\overline{X}_{GCM}}$$

Where $x_i$ and $x'_i$ are raw and corrected GCM scenarios on day i, and $X_{GCM}$ and $X_{obs}$ mean monthly mean weather data from the GCM and observations

Soil moisture deficit index (SMDI)

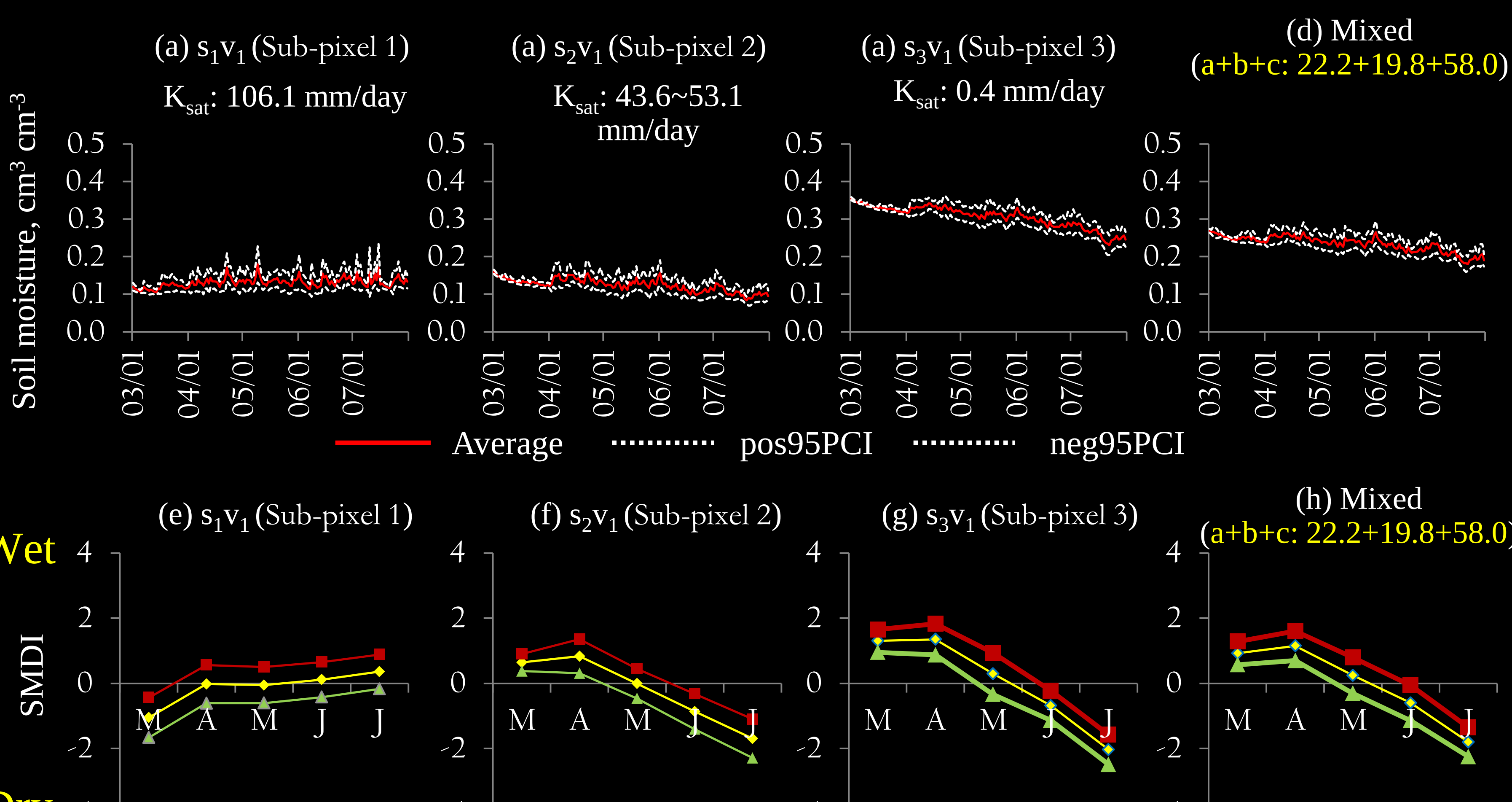
$$SMDI_j = 0.5 \times SMDI_{j-1} + \frac{SD_j}{50}$$

$$SD_{i,j} = \frac{SW_{i,j} - MSW_j}{MSW_j - \min SW_j} \times 100, \text{if} \quad SW_{i,j} = MSW_j$$

$$SD_{i,j} = \frac{SW_{i,j} - MSW_j}{\max SW_j - \min SW_j} \times 100, \text{if} \quad SW_{i,j} \rangle MSW_j$$

# Results

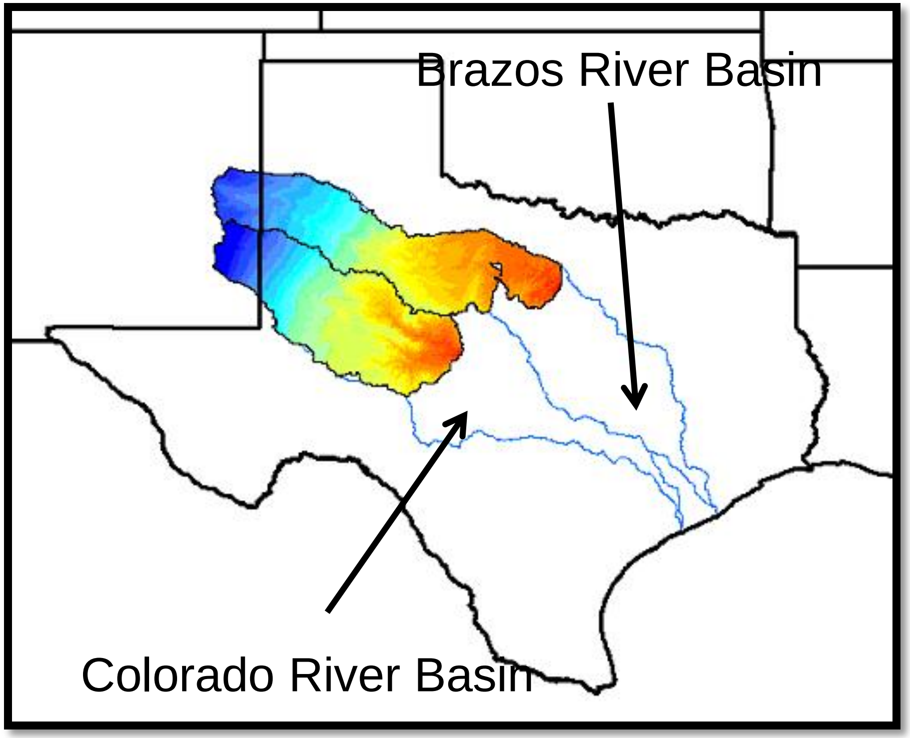
- Predicted root zone soil moisture at the WC1 site during 2010-2020



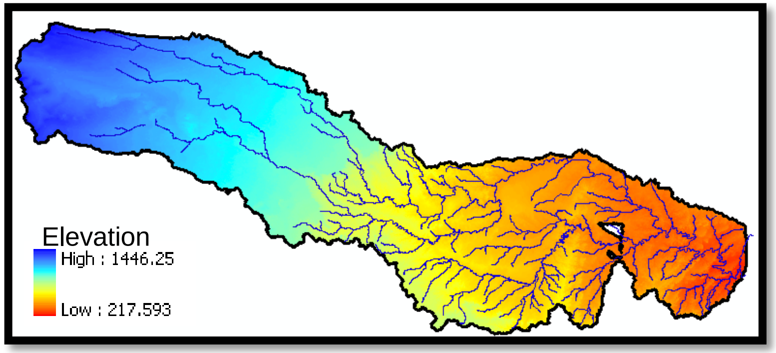

**Although the SMDI values have some uncertainties, this results showed that the sub-pixels within the RS product can be partially affected by the drought severity.**

# Soil moisture estimates in Northern Texas

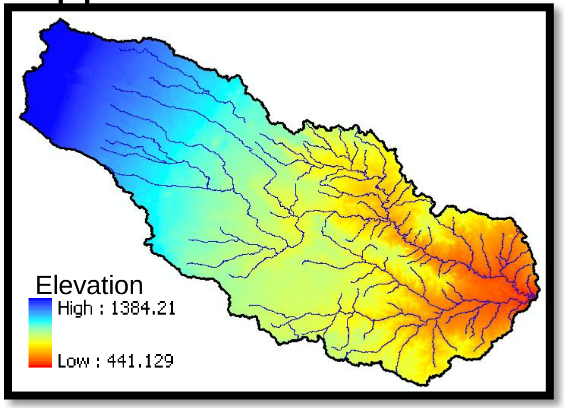
- **Estimating soil moisture dynamics using land surface model (Community Land Model, CLM)**




Upper Brazos river




Upper Colorado river



# Ongoing work…

- **Improve subsurface process including soil moisture interaction with groundwater in the land surface models (CLM)**

- **Develop scaling approach for hydraulic parameters of hydrologic components (surface, subsurface, and recharge/discharge)**

- **Forecast drought severity using the Bayesian multi-scale averaging of land surface models at regional scale in Texas**