Challenges and Opportunities of Creating a High-resolution Soil Moisture Map for Kansas

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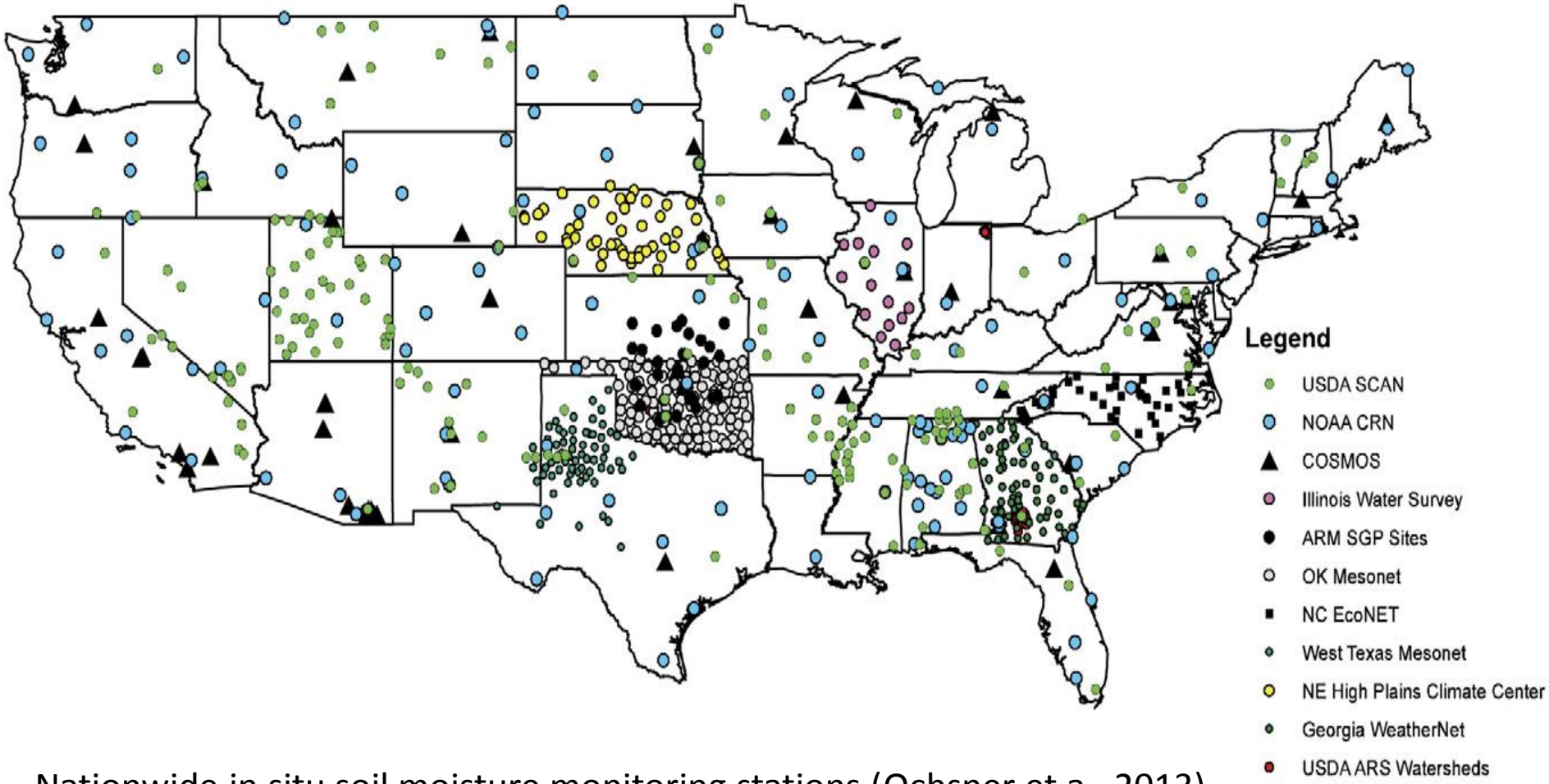
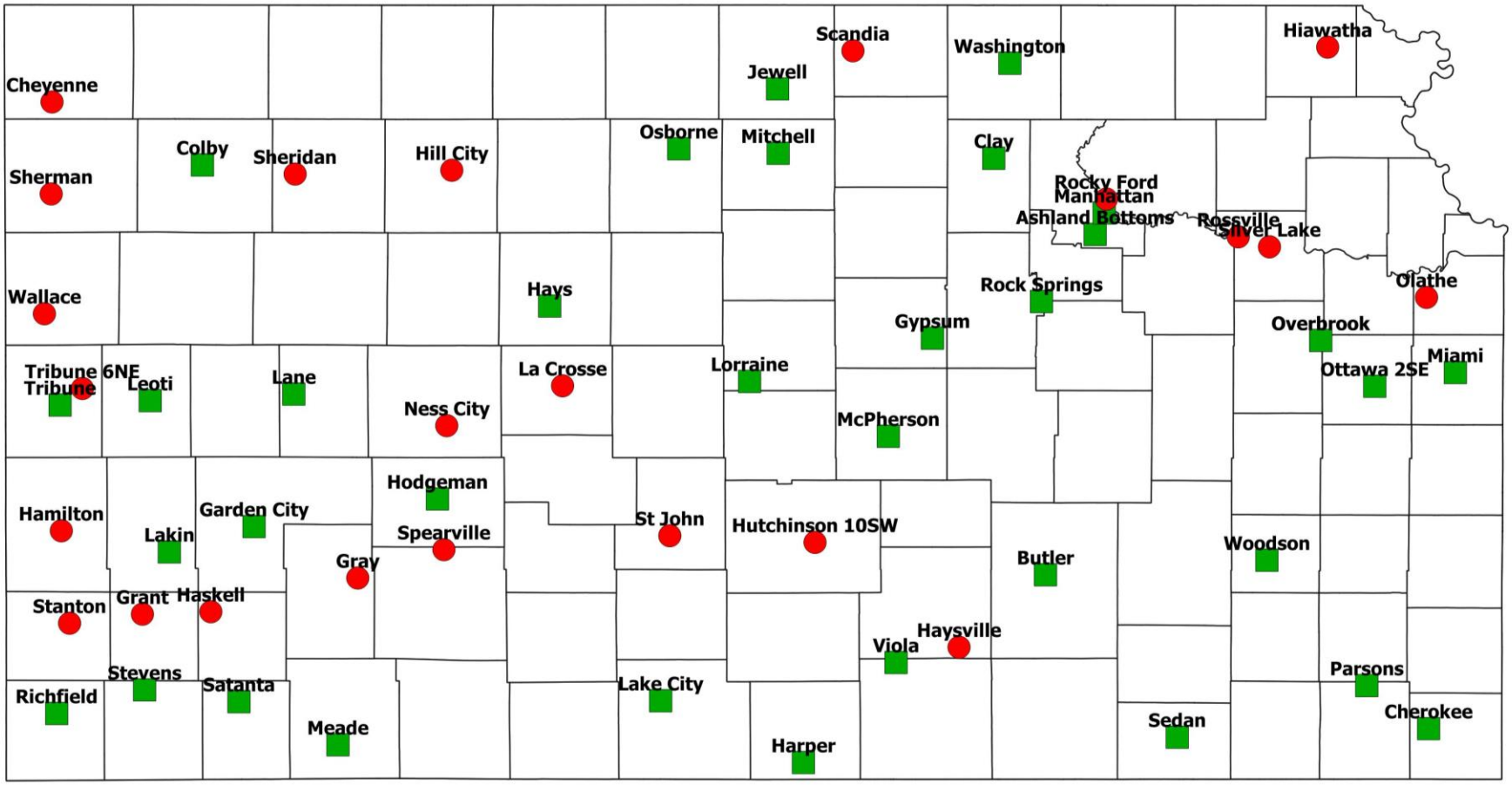
US Soil Moisture Monitoring Stations



Nationwide in situ soil moisture monitoring stations (Ochsner et a., 2013).

Kansas In-situ Monitoring Stations



Station Type

- 10ft Tripod
- 30' Tower

0 50 100 miles

North

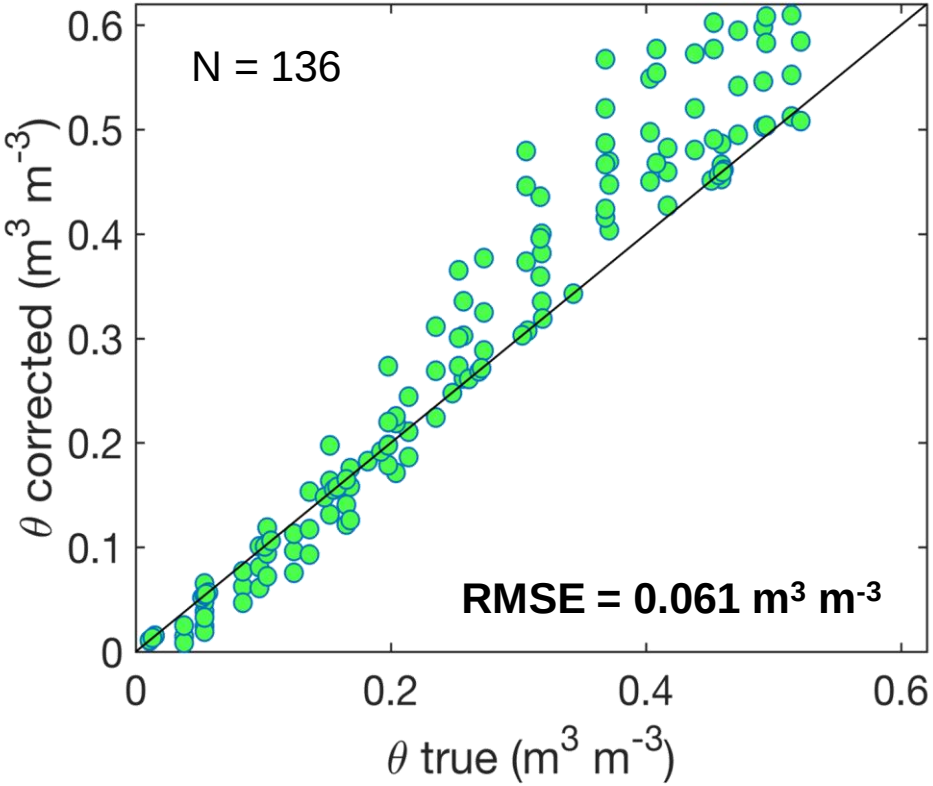
Kansas State University Weather Data Llibrary (WDL) Weather Station Mesonet
As of: 9/26/17
Created by: Christopher Redmond - WDL Manager
christopherredmond@k-state.edu
785-532-3029/785-477-6204
mesonet.k-state.edu

In situ Monitoring Stations

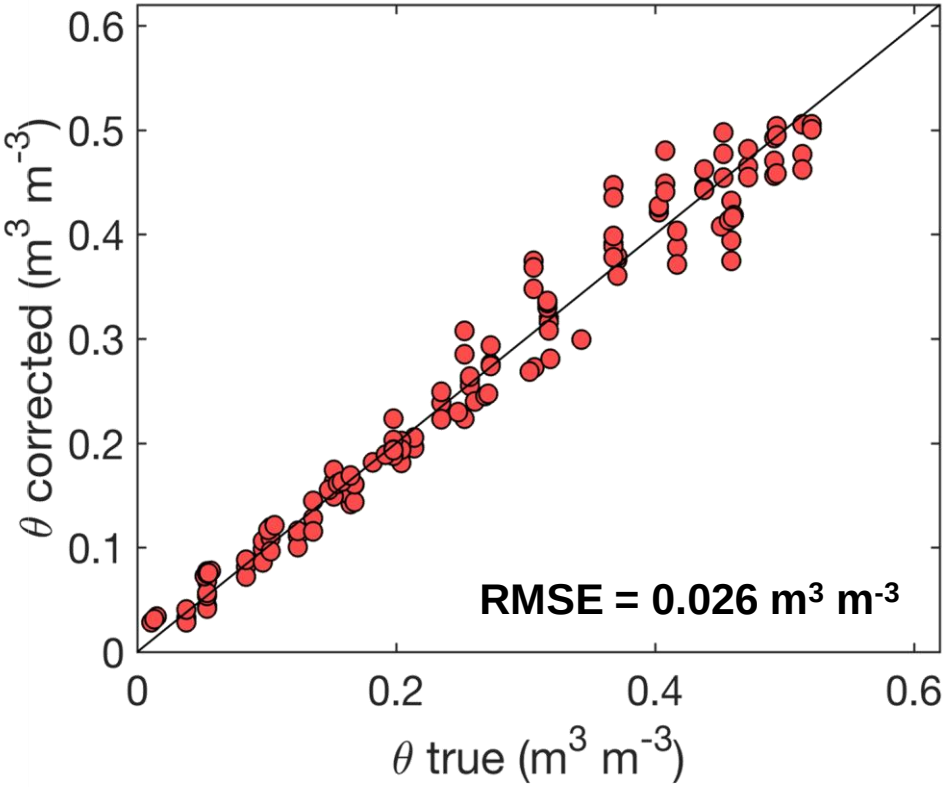
- Readily avialable ground-truth observations.
- Campbell Scientific 655 soil water reflectometer.
- Sensors deployed at 5, 10, 20 , and 50 cm depth.
- Laboratory custom calibration equation.

In situ Monitoring Stations

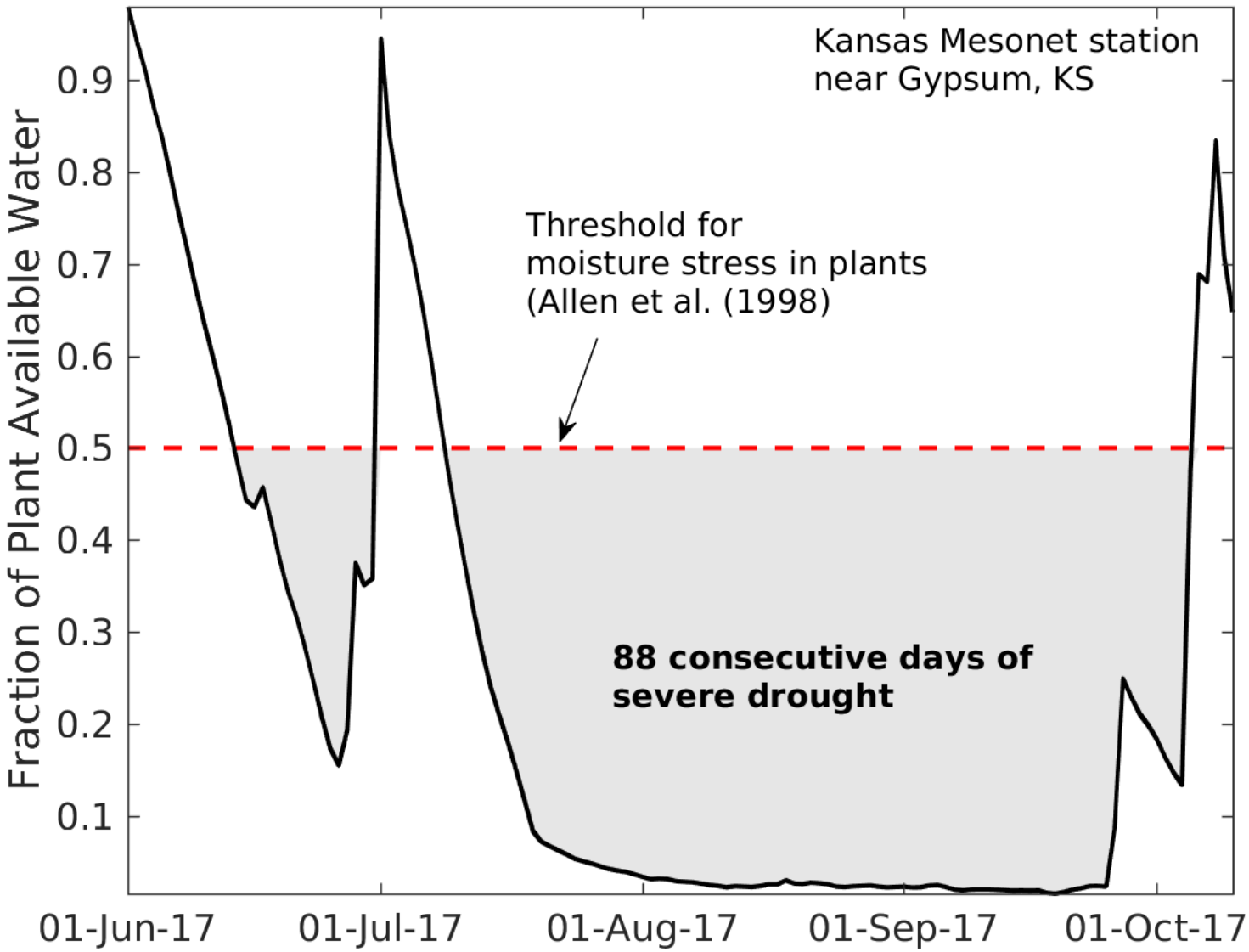
Factory default
(Topp et al. 1980)



Custom calibration
$\theta_{corrected} = A + B\sqrt{\varepsilon'} + C\,T\varepsilon'$

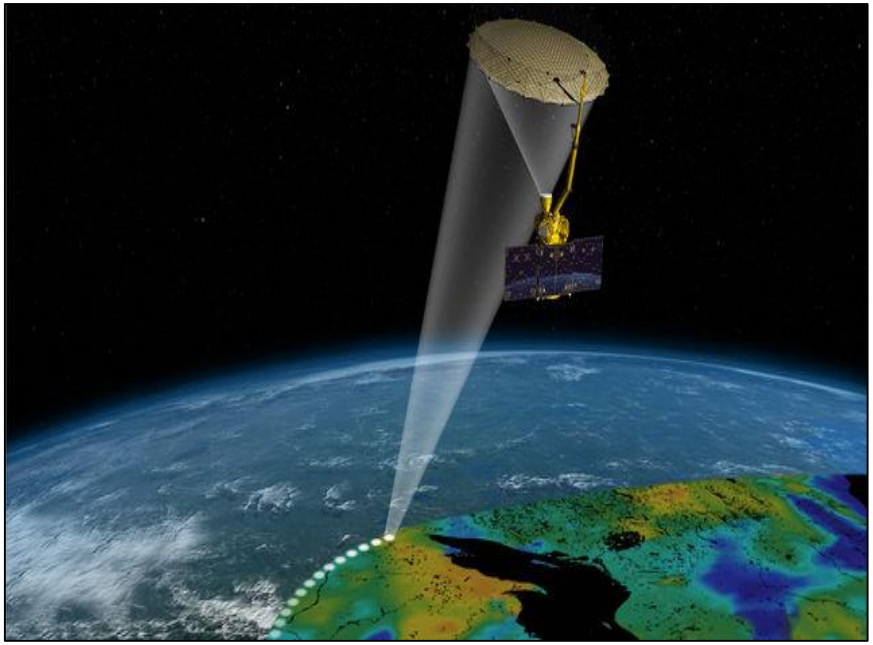


Default (**left**) and custom (**right**) calibration equations for the CS655 soil water reflectometer.



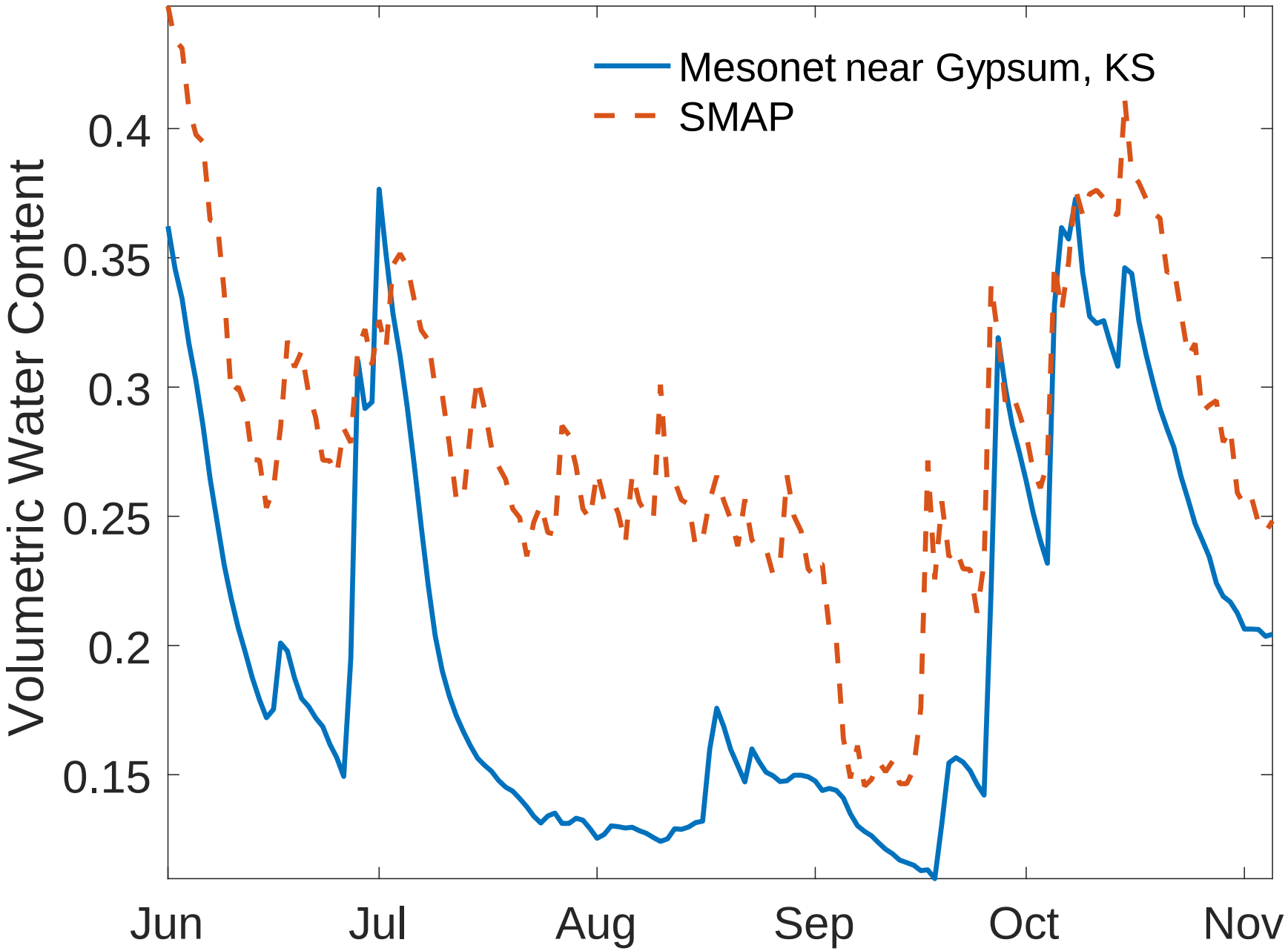
Fraction of available water capacity in the root-zone (top 50 cm of the soil profile) for the Kansas Mesonet station located near Gypsum, KS.

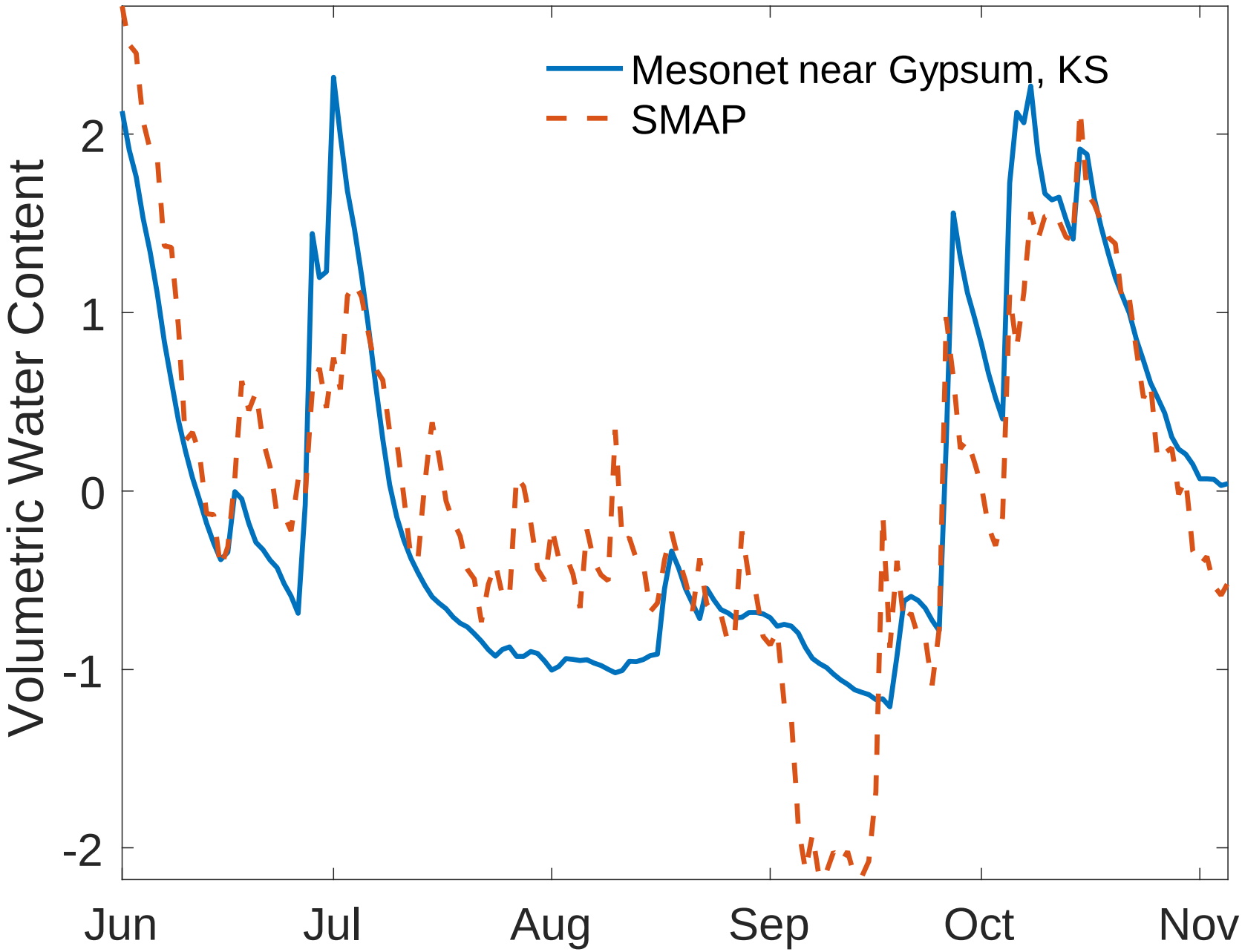
Remote Sensing Soil Moisture



NASA **S**oil **M**oisture **A**ctive-**P**assive (SMAP) mission.

- Measures top 5 cm of the soil profile.
- Latency of 2-3 days.
- Coarse grid of 36 x 36 km (<200 pixels to cover the state of Kansas).
- Daily products at 9x9 km when assimilated with land surface models.
- Ideal for large scale (i.e. nation, global) monitoring.


Mesonet near Gypsum, KS
SMAP
Volumetric Water Content
0.4
0.35
0.3
0.25
0.2
0.15
Jun
Jul
Aug
Sep
Oct
Nov


Mesonet near Gypsum, KS
SMAP
Volumetric Water Content
2
1
0
-1
-2
Jun
Jul
Aug
Sep
Oct
Nov

Modeling Soil Moisture Dynamics

Soil moisture diagnostic equation:

$$\theta = \theta_{re} + (\phi_e - \theta_{re})(1 - e^{-c_4 B})$$

θ = Volumetric water content [$m^3\ m^{-3}$]

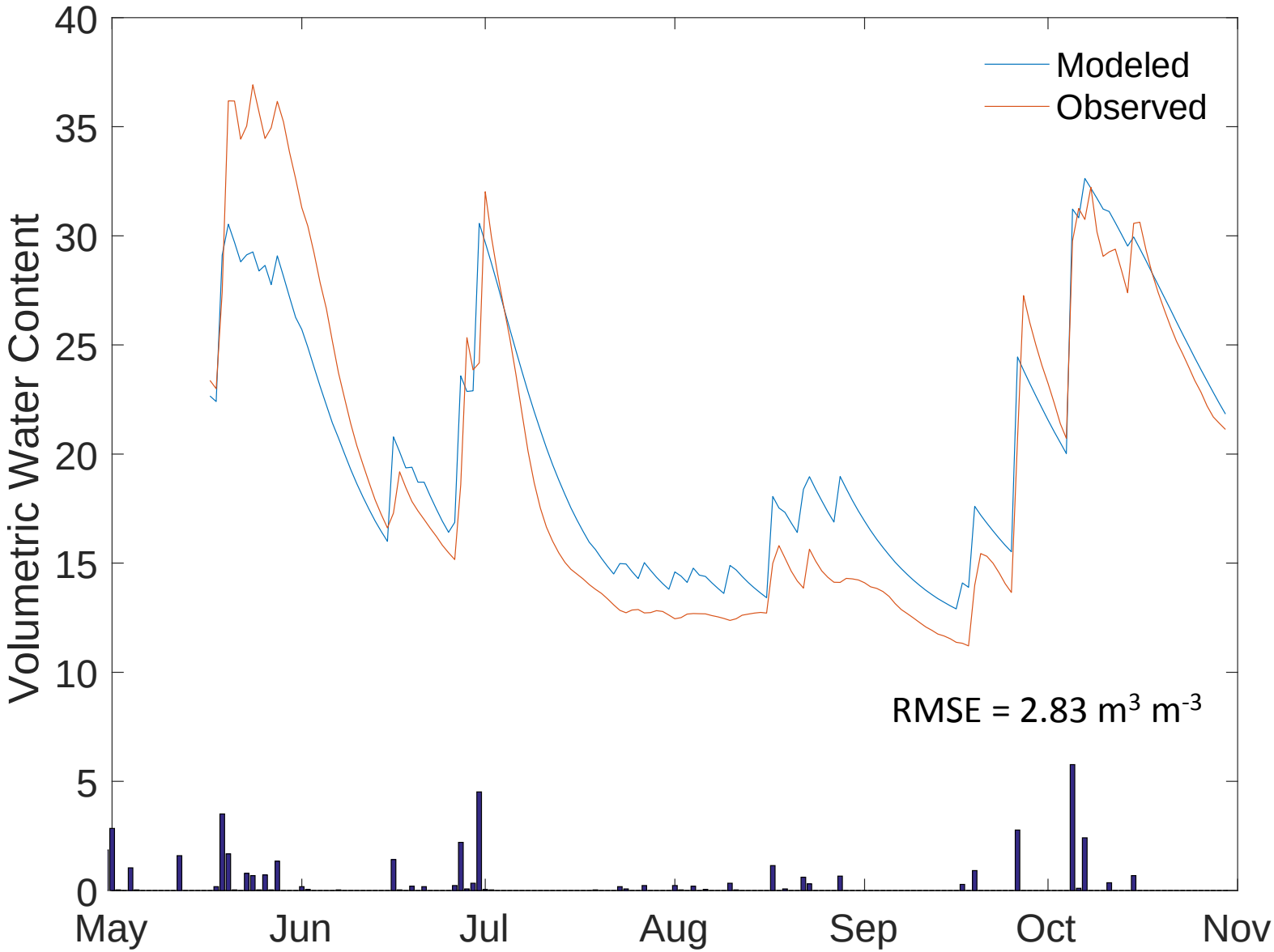
θ_{re} = Residual water content [$m^3\ m^{-3}$]

θ_e = Effective porosity [$m^3\ m^{-3}$]

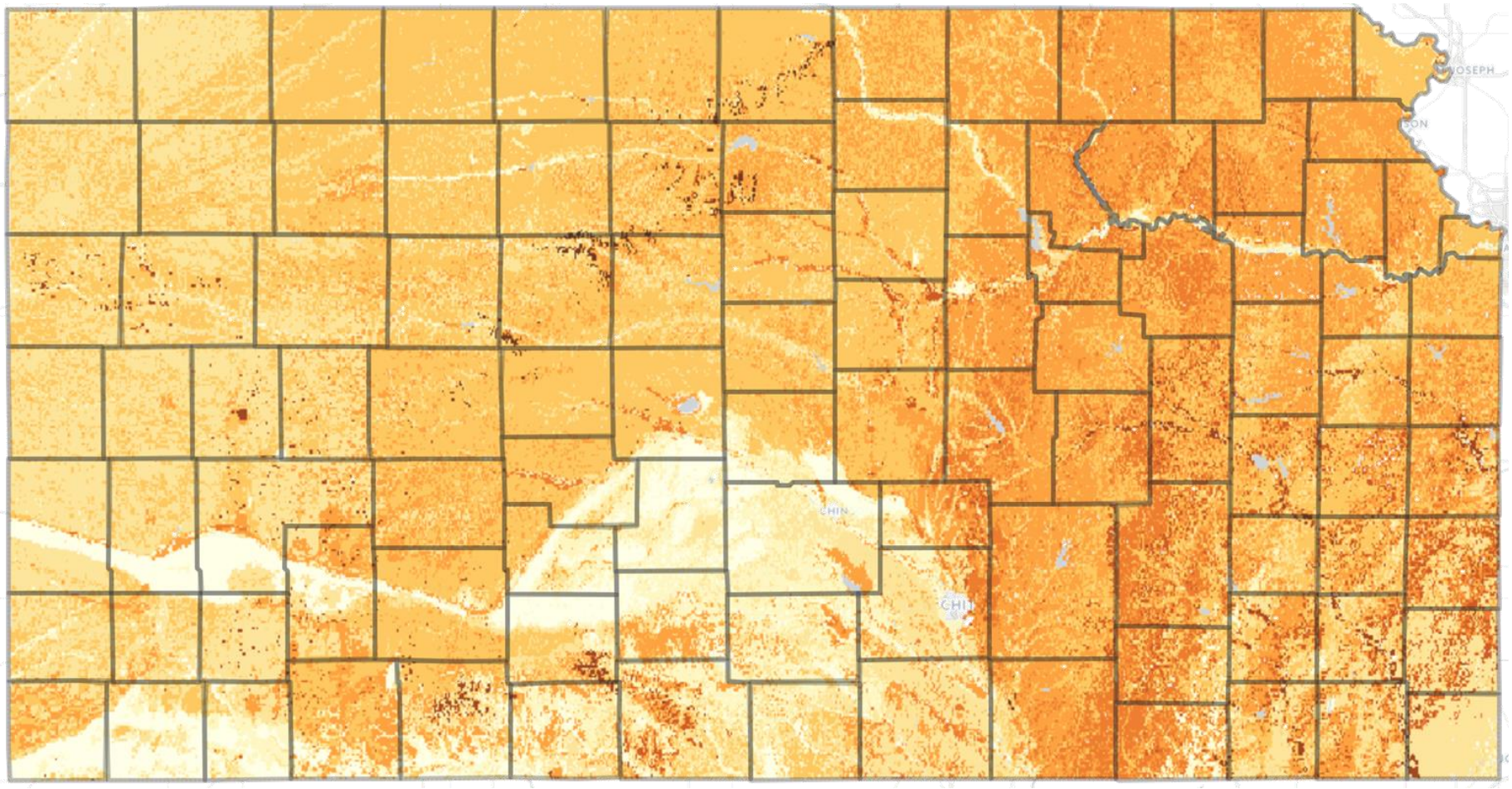
C_4 = Parameter that depends on the soil physical properties

B = Exponential filter applied to a precipitation timeseries

Entekhabi, D., and I. Rodriguez-Iturbe, Analytical framework for the characterization of the space-time variability of soil moisture, *Adv. Water Resour.*, **17**, 35–45, 1994.

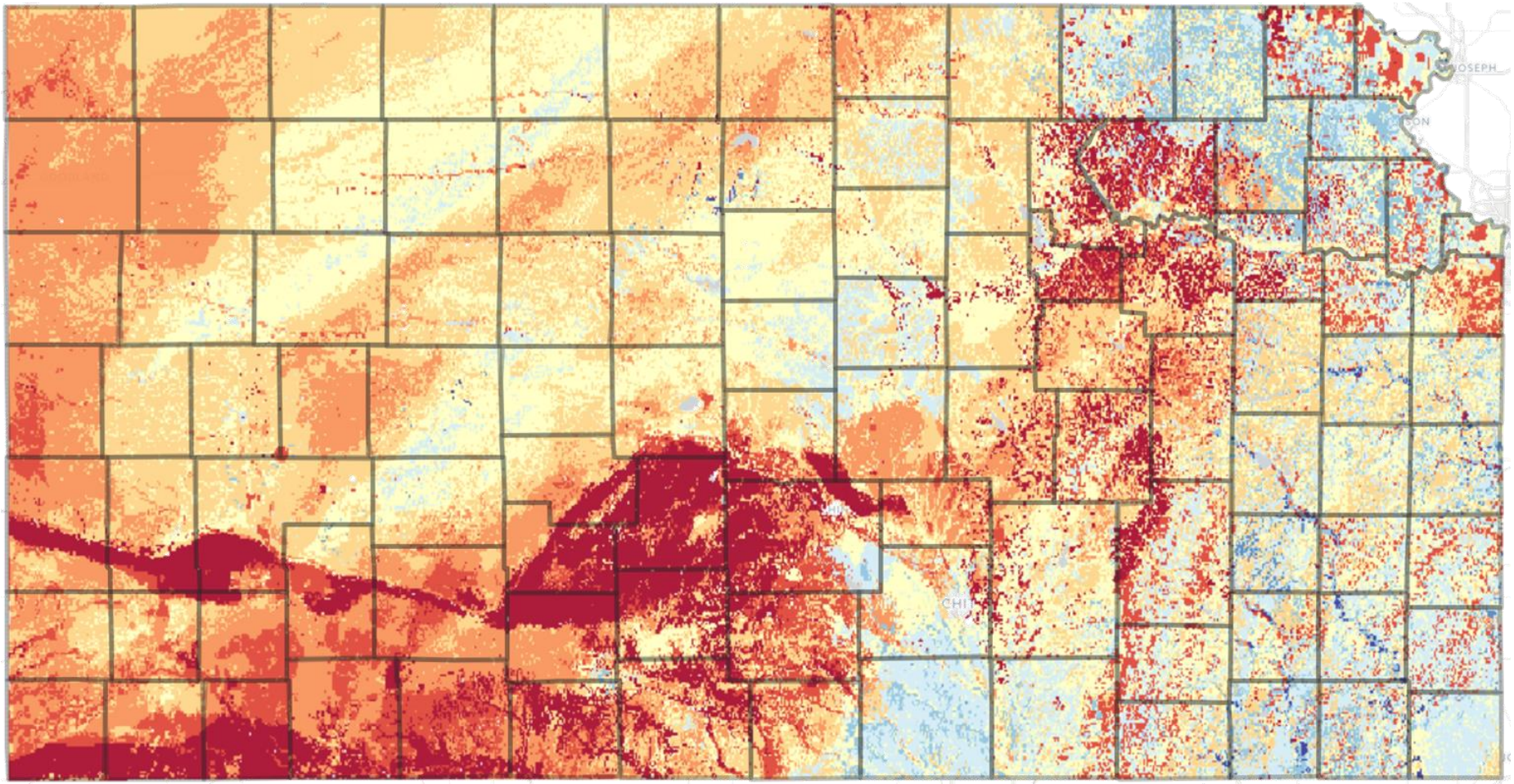

Modeled
Observed
RMSE = 2.83 m^3 m^{-3}
Volumetric Water Content
40
35
30
25
20
15
10
5
0
May
Jun
Jul
Aug
Sep
Oct
Nov

Soil Physical Properties Spatial Variability



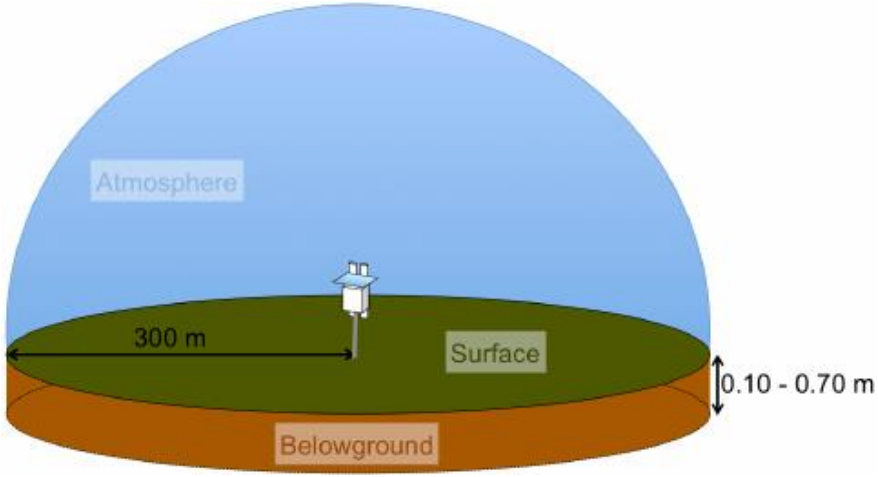
Map of percent clay content in the top 5 cm at 800 m resolution for the state of Kansas. Darker colors represent higher clay content. Source: USDA-NRCS Soil Survey Geodatabase.

First Statewide Soil Moisture Map (0-5 cm)



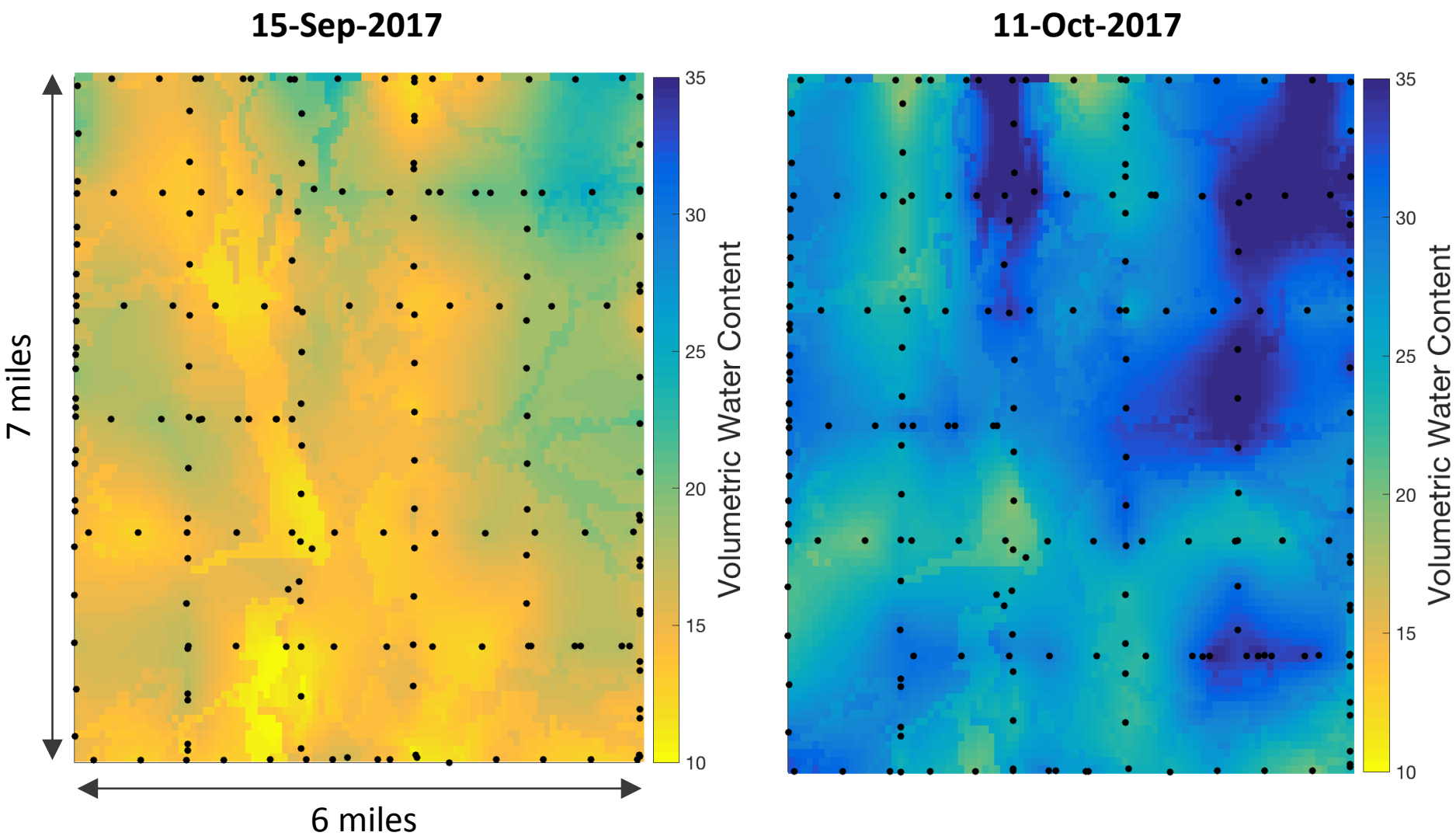
Map of fraction of plant available water capacity in the top 5 cm at 800 m resolution for the state of Kansas. Source: soilwater.ksu.edu

Proximal sensing using Cosmic-ray Neutrons



Approximate COSMOS footprint (**top**) and KSU roving detector (**bottom**)

- **CO**smic-ray neutrons **S**oil **M**oisture **O**bserving **S**ystem (COSMOS).
- Monitors background fast-moving neutrons generated at the top of the atmosphere by the impingement of galactic cosmic-ray protons.
- Emerging technology with large sensing footprint (250-300 m in radius).
- Stationary probes and roving probes ideal for field-scale and landscape-scale observations.



Maps of volumetric water content of a 9x9 km SMAP grid cell measured with a roving cosmic-ray neutron probe near Gypsum, KS before (**left**) and after (**right**) a series of rainfall events totaling 97 mm. Black markers represent rover measurements (N=220).

Challenges

- **Lack of guidelines** and standards for soil moisture monitoring across large-scale networks.
- Large-scale networks only monitor soil moisture under grassland vegetation. How do we **upscale** point-level observation to represent different land covers?
- **Downscaling** remote sensing coarse grids for field or watershed studies that often require finer resolution and knowledge of root-zone soil moisture.
- **Emerging technologies** still require simpler **calibration** and **validation** methods.
- **Spatial characterization** soil physical properties.