State of in-situ Soil Moisture Monitoring at the Kansas Mesonet

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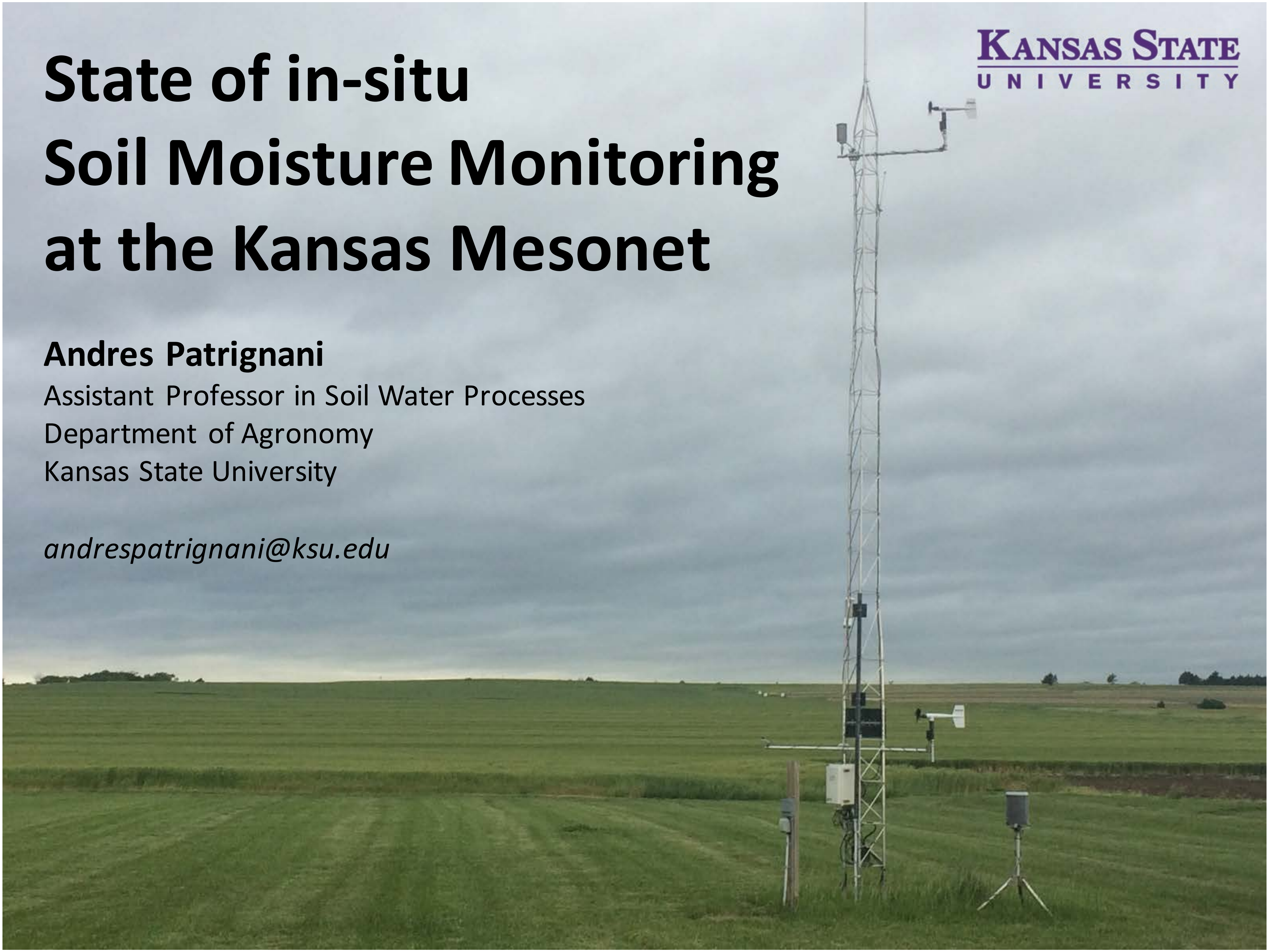
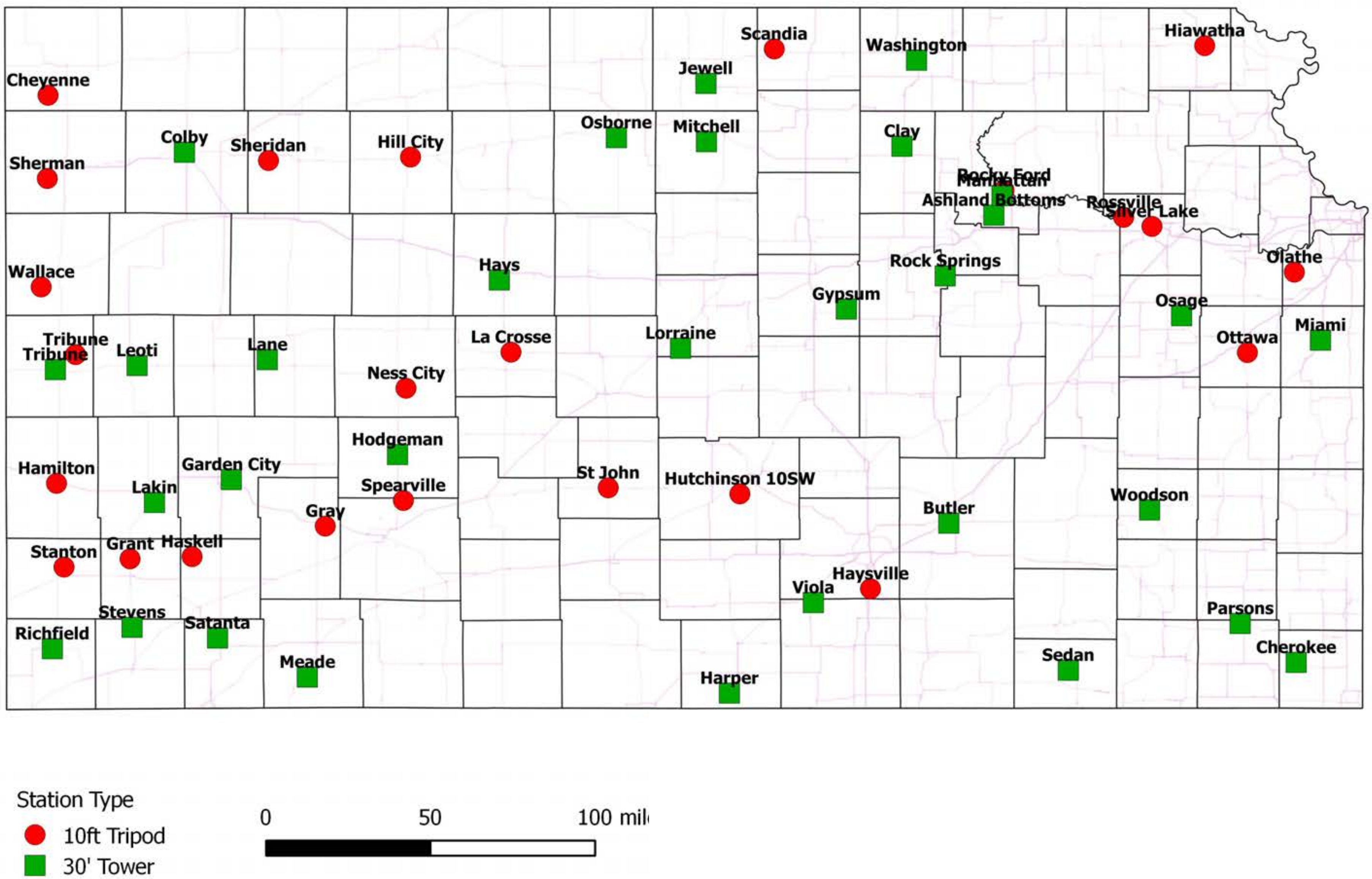


Brief History of the Kansas Mesonet

- **Established in 1986** by the Kansas Research and Extension (visit mesonet.k-state.edu)
- From 13 stations in 1986 to **60 stations in 2018**
- Currently **managed by** Weather Data Library under the **Department of Agronomy**
- In the past year **we deployed soil moisture sensors** (CS655) **at 22 stations**

Current Kansas Mesonet Stations



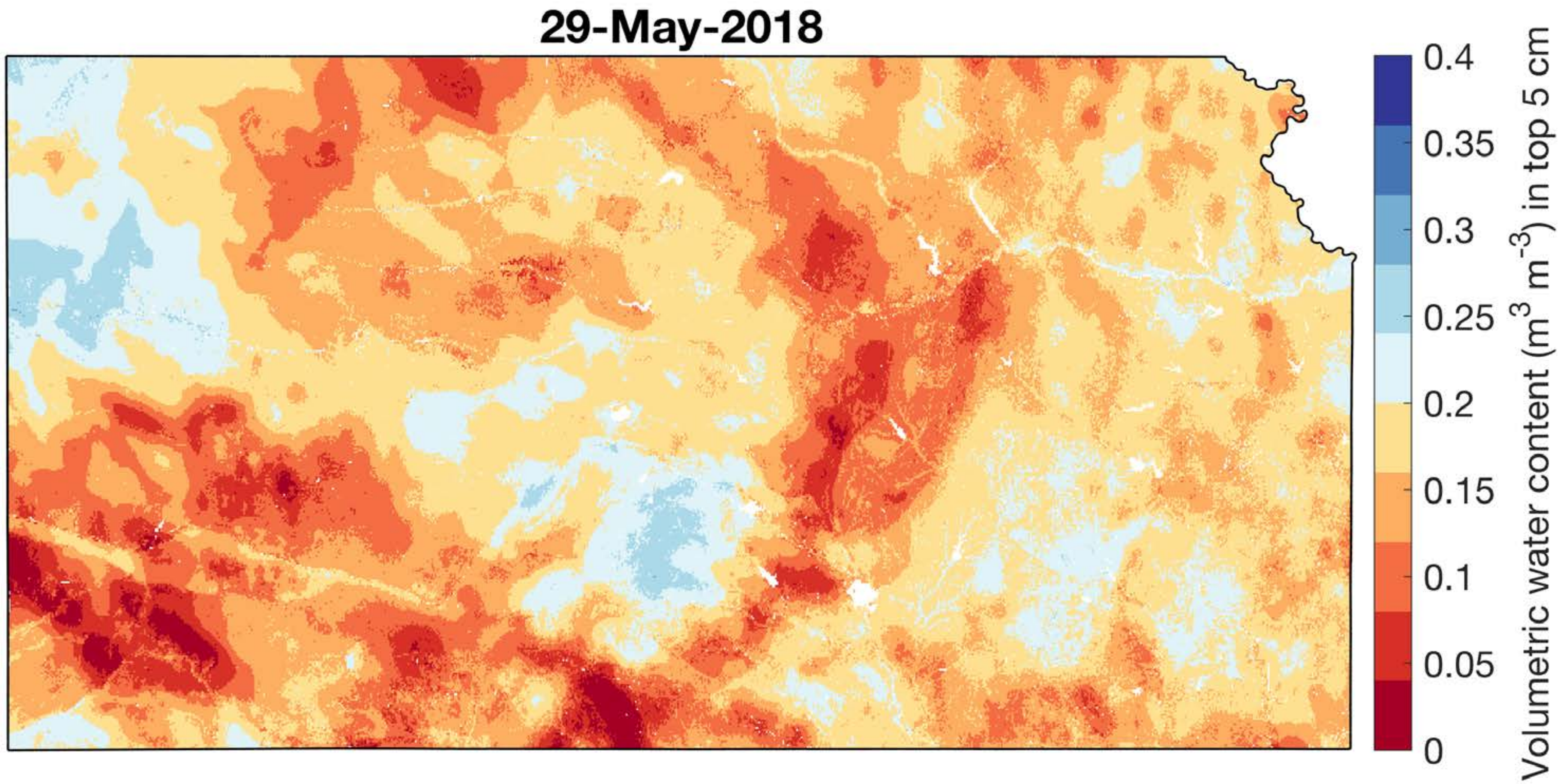
Network Variables

Current variable	Height/depth	Observation frequency
Precipitation	0.5 m	1-min, 5-min, hourly, daily
Air temperature	2.0 m	5-min, hourly, daily
Air temperature	**10 m**	**5-min, hourly, daily**
Barometric pressure	1.5 m	1-min, 5-min, hourly, daily
Relative humidity	2.0 m	5-min, hourly, daily
Wind speed	2.0 m and 10.0 m	1-min, 5-min, hourly, daily
Wind direction	2.0 m and 10.0 m	5-min, hourly, daily
Incoming solar radiation	2.0 m	5-min, hourly, daily
Soil temperature	5, 10 cm depth	5-min, hourly, daily
Soil temperature (CS655)	**5, 10, 20, 50 cm depth**	**5-min, hourly, daily**
Soil moisture (CS655)	**5, 10, 20, 50 cm depth**	**5-min, hourly, daily**

Future (from MOISST 2017)

- Deploy soil moisture sensors in 22 stations with towers during the summer 2017.
- Where do we install the next station?
- Upgrade tripods to towers.
- Create a statewide soil moisture map
- Add soil moisture to the web API.

A Statewide Map of Soil Moisture



Gridded 800-meter resolution map of soil moisture at 5 cm depth.

Building the Map

- **Soil moisture diagnostic equation** (Daily time steps).

$$\theta_{pred} = \boldsymbol{\theta_{res}} + (\boldsymbol{\theta_{sat}} - \boldsymbol{\theta_{res}})\left(1 - e^{-C_4 \boldsymbol{\beta}}\right)$$

- Soil moisture is estimated as the time-weighted average of preceding rainfall (similar to Antecedent Precipitation Index)

- Bounded between residual and saturation water content

- Does not require knowledge of initial conditions

Pan, F., Peters-Lidard, C.D. and Sale, M.J., 2003. An analytical method for predicting surface soil moisture from rainfall observations. *Water Resources Research*, *39*(11).

Soil moisture diagnostic equation

Step 1: Time-weighted sum of precipitation events (dimensionless)

$$\beta = \sum_{i=2}^{i=n-1} \left[\frac{P_i}{\eta_i} \left(1 - e^{\frac{\eta_i}{z}}\right) e^{-\sum_{j=1}^{j=i-1} \left(\frac{\eta_j}{z}\right)} \right] + \frac{P_1}{\eta_1} \left(1 - e^{\frac{\eta_1}{z}}\right)$$

Precipitation source: 4-km gridded rainfall product from Parameter elevation regression on Independent Slopes Model (PRISM) http://www.prism.oregonstate.edu/

Loss coefficient

$$\eta_i = C_1 + C_2 \sin\left[\frac{2\pi\left(DOY_i + C_3 + \frac{\pi}{2}\right)}{365}\right]$$

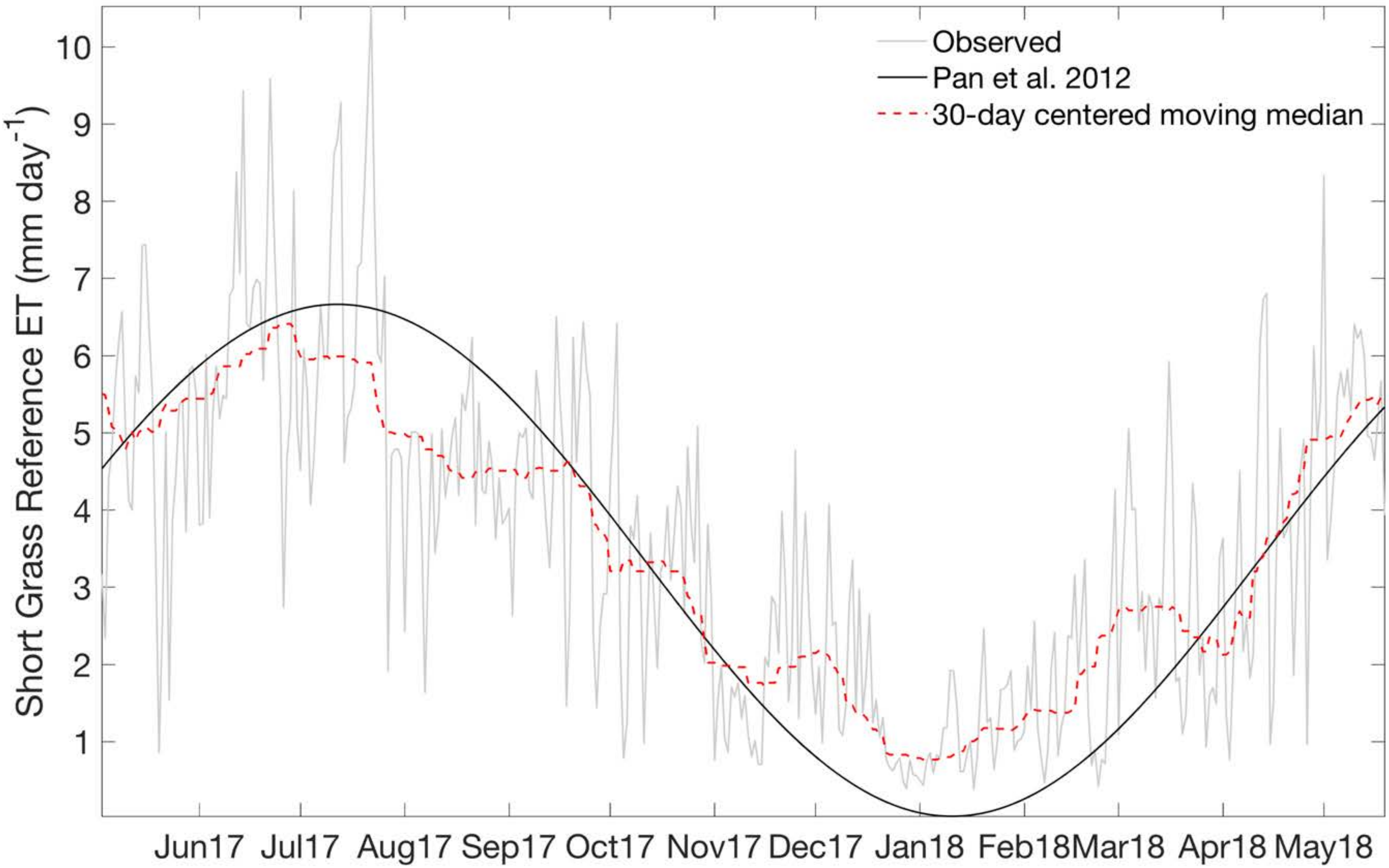
C_1 = Mean annual reference ET from Kansas Mesonet stations

C_2 = Reference ET annual amplitude from Kansas Mesonet stations

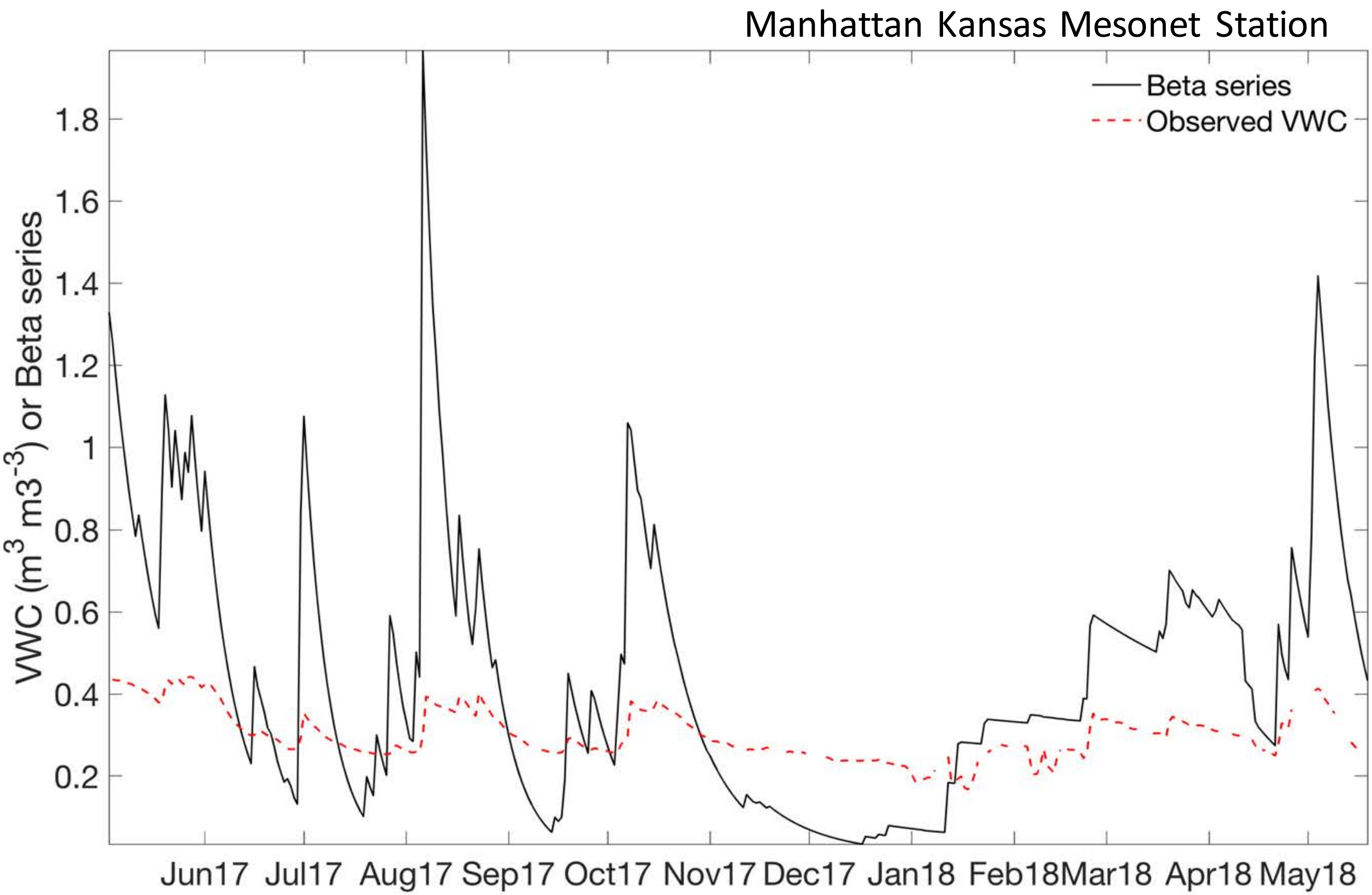
C_3 = Phase constant. DOY of maximum reference ET

Example Loss Coefficient

Manhattan Kansas Mesonet Station



Example Beta series (dimensionless)



Soil moisture diagnostic equation

Step 1: Time-weighted sum of precipitation events (dimensionless)

$$\beta = \sum_{i=2}^{i=n-1} \left[\frac{P_i}{\eta_i}\left(1 - e^{\frac{\eta_i}{z}}\right) e^{-\sum_{j=1}^{j=i-1}\left(\frac{\eta_j}{z}\right)}\right] + \frac{P_1}{\eta_1}\left(1 - e^{\frac{\eta_1}{z}}\right)$$

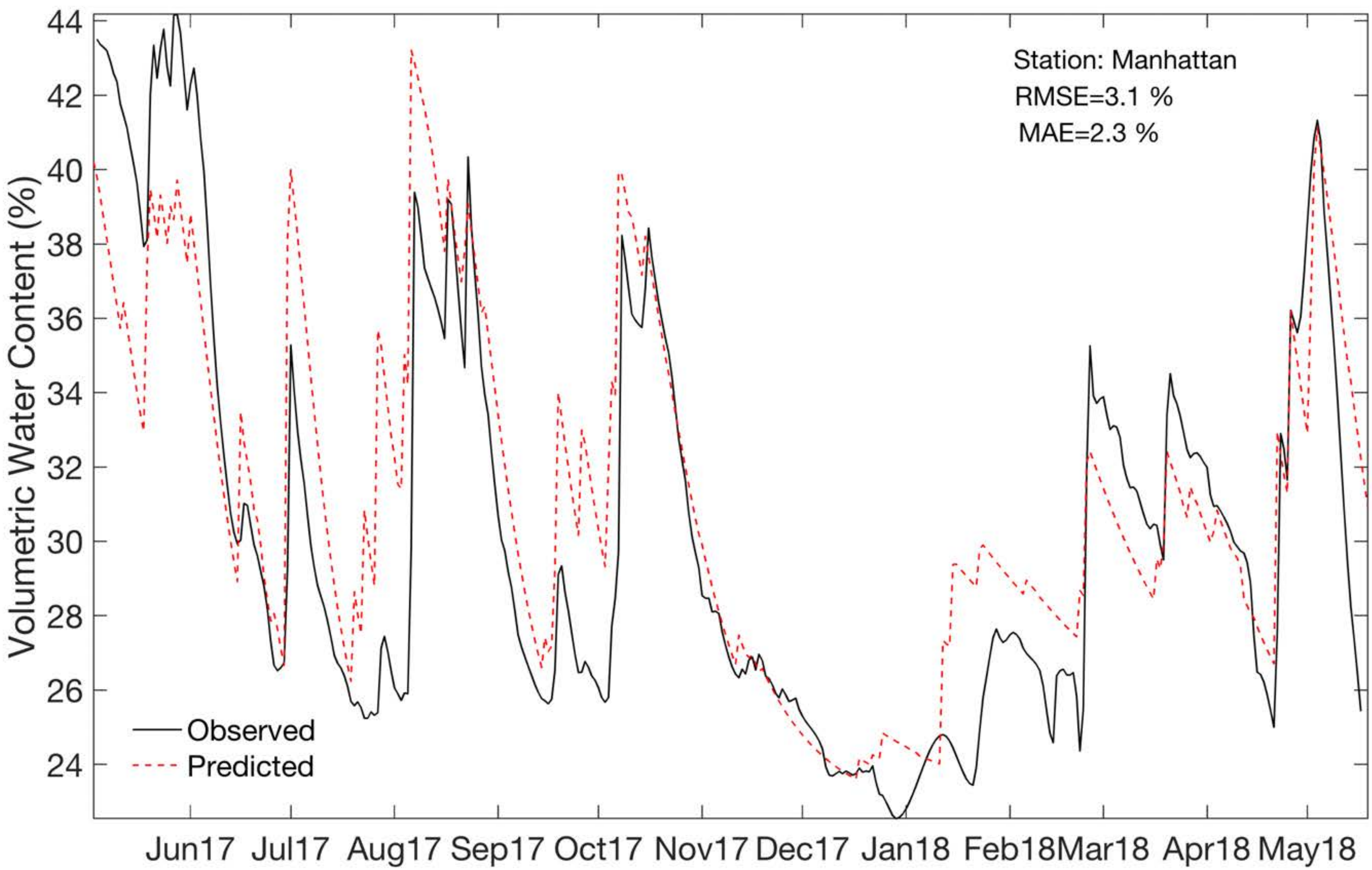
Loss coefficient (simplified atmospheric demand, cm per day)

$$\eta_i = C_1 + C_2 \sin\left[\frac{2\pi\left(DOY_i + C_3 + \frac{\pi}{2}\right)}{365}\right]$$

Step 2: Soil moisture Diagnostic Equation

$$\theta_{pred} = \theta_{res} + (\theta_{sat} - \theta_{res})\left(1 - e^{-\mathbf{C_4}\beta}\right)$$

Soil moisture diagnostic equation



Model Evaluation Using USCRN

Using all available soil moisture data since station deployment to December 2017

Soil layer (cm)	Number of USCRN stations	RMSE (% VWC)	MAE (% VWC)
0-5 cm	63	4.55	3.46
0-10 cm	67	4.27	3.27
0-20 cm	60	4.08	3.19
0-50 cm	58	3.71	2.92
0-100 cm	52	3.34	2.57

USCRN: US Climate Reference Network
RMSE: Root Mean Squared Error
MAE: Mean Absolute Error

Soil moisture diagnostic equation

Step 1: Time-weighted sum of precipitation events (dimensionless)

$$\beta = \sum_{i=2}^{i=n-1} \left[\frac{P_i}{\eta_i}\left(1 - e^{\frac{\eta_i}{z}}\right) e^{-\sum_{j=1}^{j=i-1}\left(\frac{\eta_j}{z}\right)}\right] + \frac{P_1}{\eta_1}\left(1 - e^{\frac{\eta_1}{z}}\right)$$

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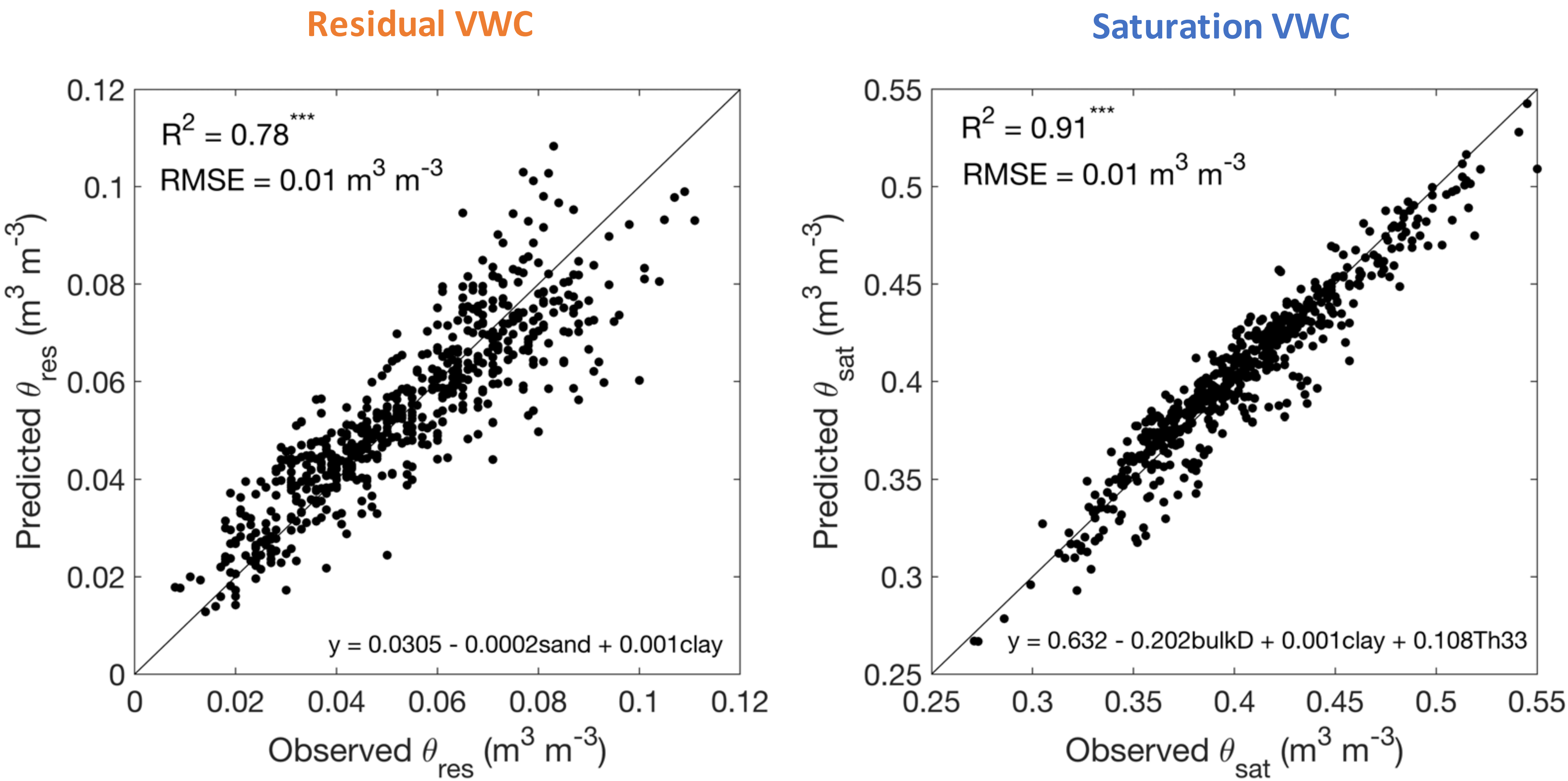
Step 2: Soil moisture Diagnostic Equation

$$\theta_{pred} = \theta_{res} + (\theta_{sat} - \theta_{res})\left(1 - e^{-C_4\beta}\right)$$

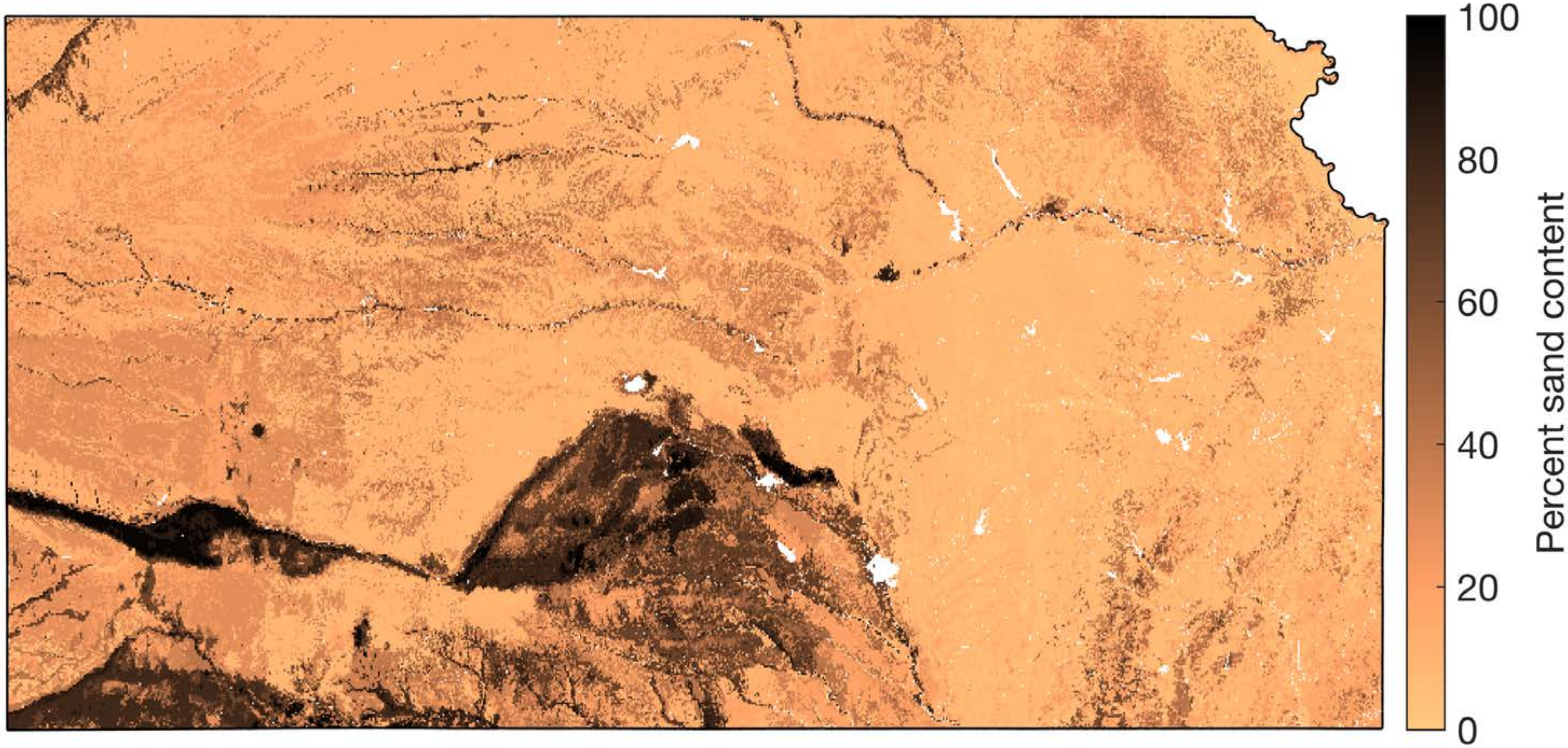
Parameter Estimation



Source: Oklahoma Mesonet soil physical properties database (http://soilphysics.okstate.edu/data)

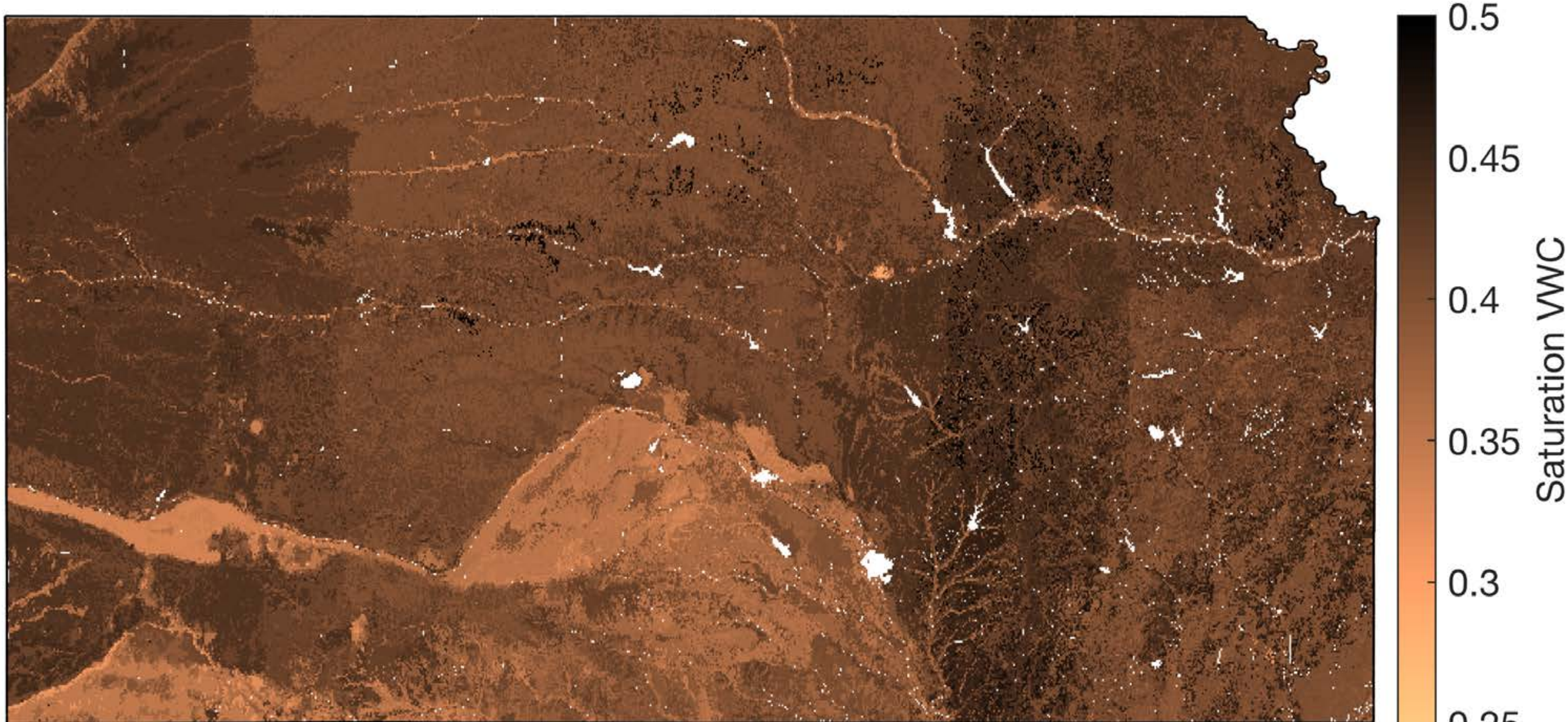
Reference: Scott, B.L., Ochsner, T.E., Illston, B.G., Fiebrich, C.A., Basara, J.B. and Sutherland, A.J., 2013. New soil property database improves Oklahoma Mesonet soil moisture estimates. *Journal of Atmospheric and Oceanic Technology*, *30*(11), pp.2585-2595.

Statewide 5-cm Percent Sand



Source: USDA-NRCS Soil Survey Database

Statewide 5-cm Saturation VWC



Source: USDA-NRCS Soil Survey Database

Soil moisture diagnostic equation

Step 1: Time-weighted sum of precipitation events (dimensionless)

$$\beta = \sum_{i=2}^{i=n-1} \left[\frac{P_i}{\eta_i}\left(1 - e^{\frac{\eta_i}{z}}\right) e^{-\sum_{j=1}^{j=i-1}\left(\frac{\eta_j}{z}\right)}\right] + \frac{P_1}{\eta_1}\left(1 - e^{\frac{\eta_1}{z}}\right)$$

Loss coefficient (simplified atmospheric demand, cm per day)

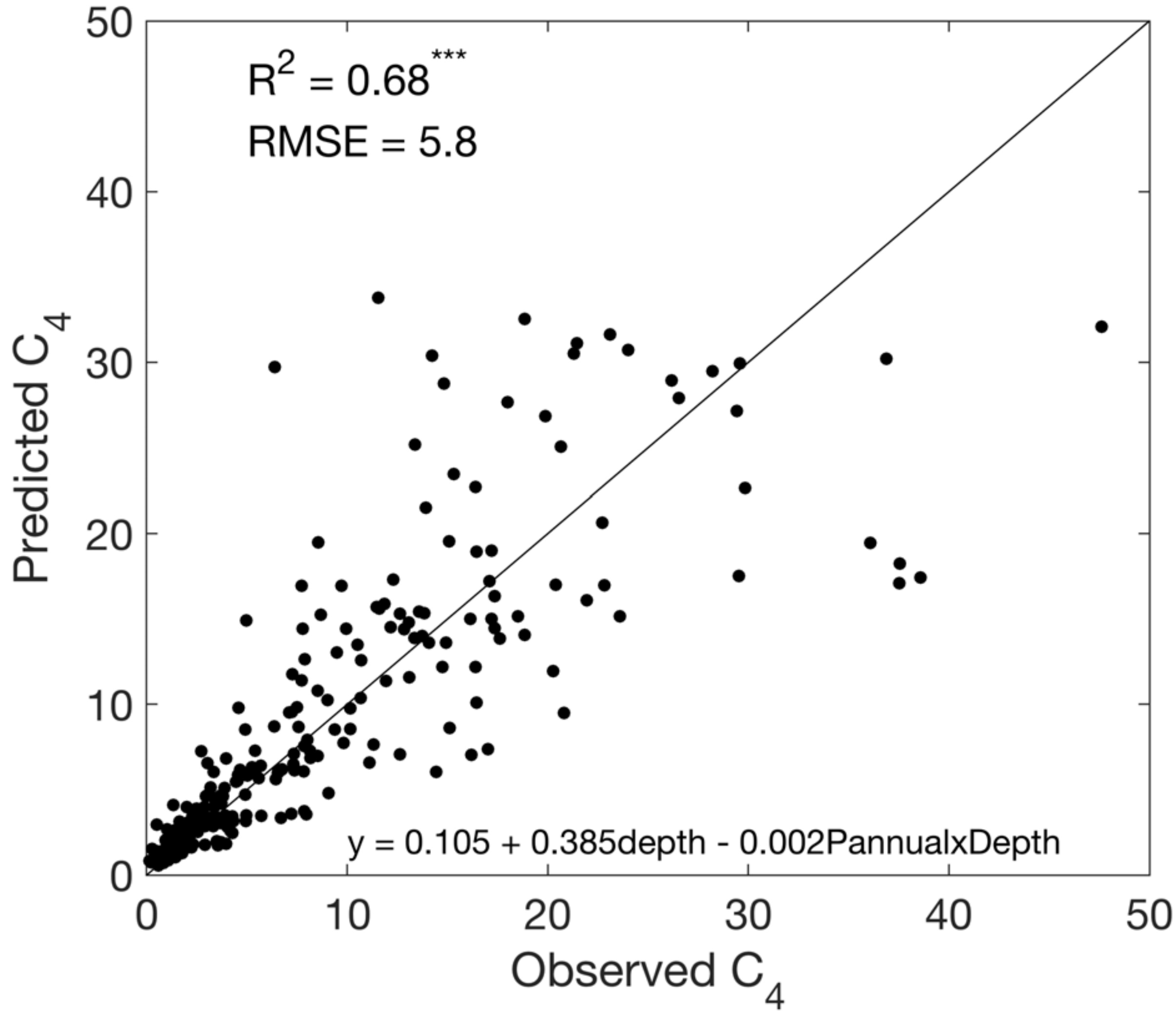
$$\eta_i = C_1 + C_2 \sin\left[\frac{2\pi\left(DOY_i + C_3 + \frac{\pi}{2}\right)}{365}\right]$$

Step 2: Soil moisture Diagnostic Equation

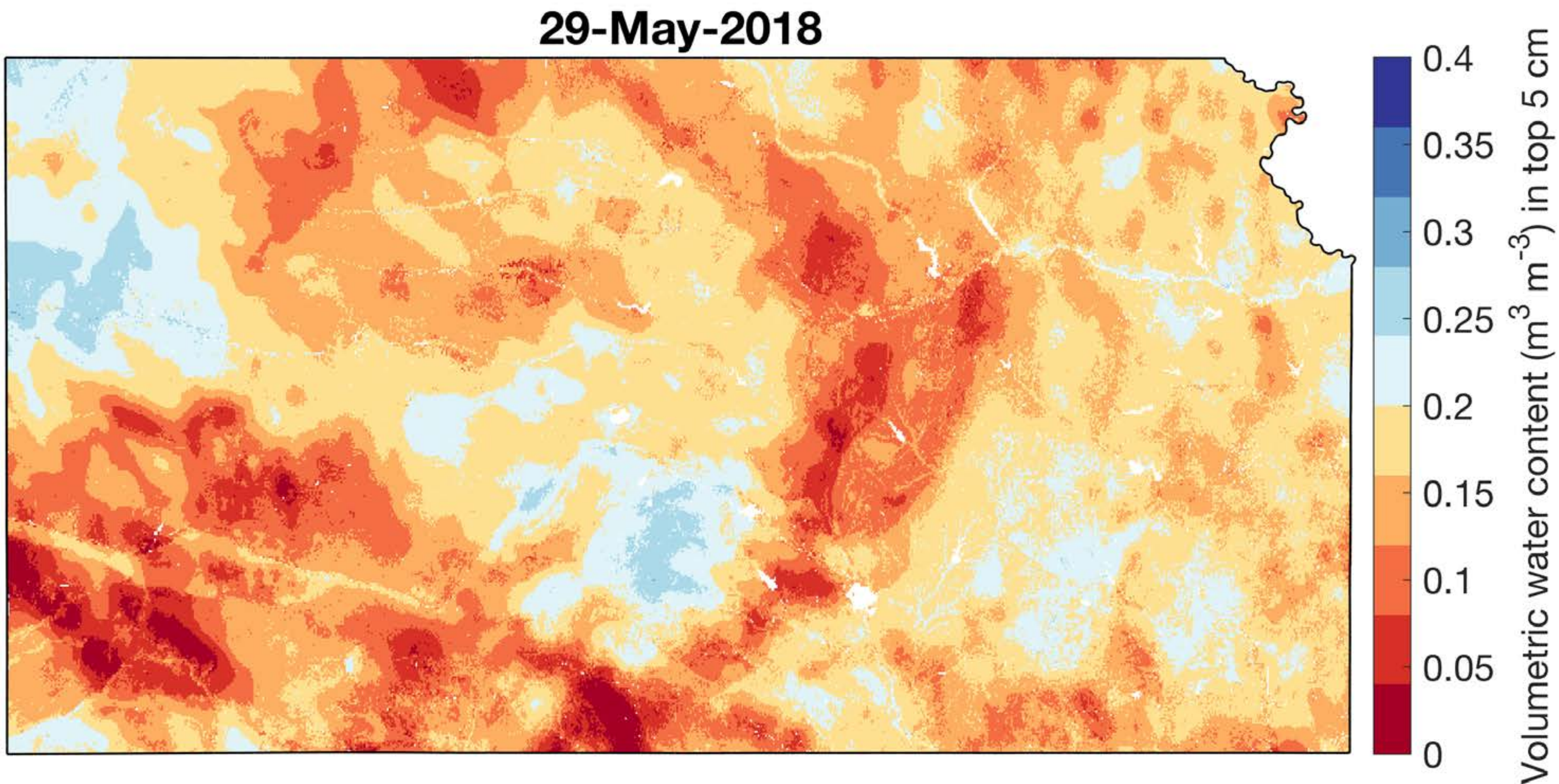
$$\theta_{pred} = \theta_{res} + (\theta_{sat} - \theta_{res})\left(1 - e^{-\boldsymbol{C_4}\beta}\right)$$

Parameter Estimation

- Estimation of C_4 parameter using US Climate Reference Network.
- C_4 parameter should be related to soil physical properties (Pan et al. 2012), but instead we found it highly correlated to precipitation regime.

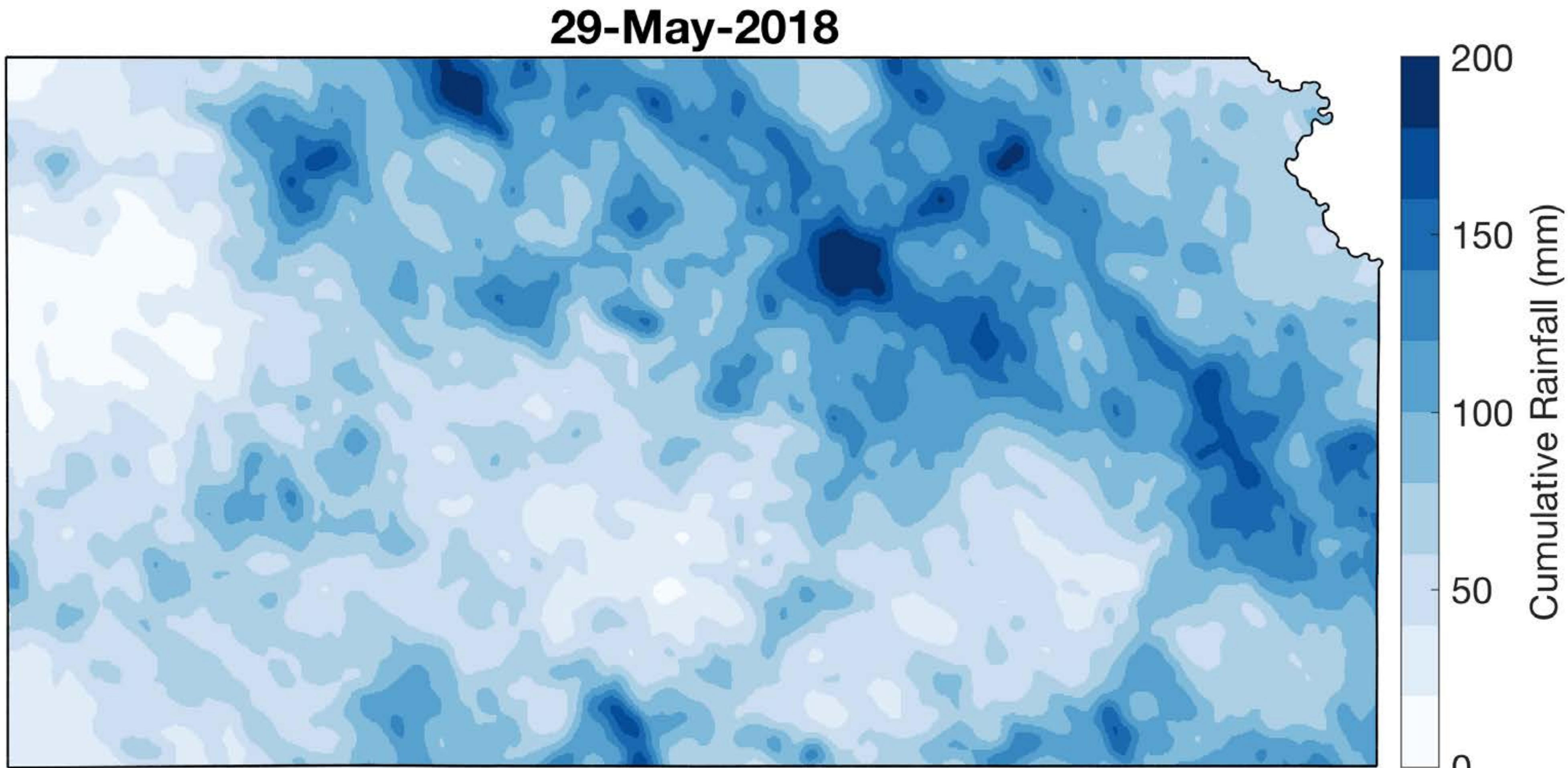


Resulting Statewide Maps



Gridded 800-meter resolution map of soil moisture at 5 cm depth.

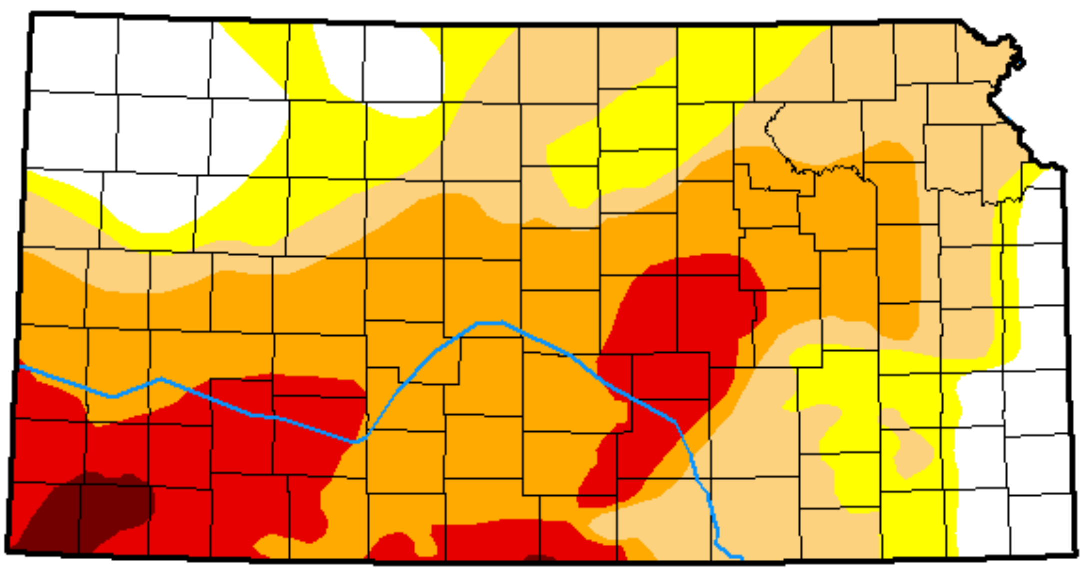
30-day Cumulative Rainfall



Gridded 800-meter resolution map of of 30-day rainfall from PRISM

U.S. Drought Monitor

Kansas



May 29, 2018

(Released Thursday, May. 31, 2018)

Valid 8 a.m. EDT

Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	15.19	84.81	69.40	45.96	15.85	1.47
Last Week *05-22-2018*	7.95	92.05	75.29	47.36	15.85	1.60
3 Months Ago *02-27-2018*	1.22	98.78	73.49	34.44	9.50	0.00
Start of Calendar Year *01-02-2018*	0.00	100.00	32.70	8.75	0.00	0.00
Start of Water Year *09-26-2017*	59.89	40.11	10.08	1.35	0.00	0.00
One Year Ago *05-30-2017*	100.00	0.00	0.00	0.00	0.00	0.00

Intensity:

- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. See accompanying text summary for forecast statements.

Author:

Anthony Artusa

NOAA/NWS/NCEP/CPC

http://droughtmonitor.unl.edu/

Summary

- The soil moisture diagnostic equation provides **parsimonious framework** for making accurate predictions of root-zone soil moisture.
- **Proven method for hindcasting** of soil moisture. **Relevant for calculating anomalies** in areas with lack of long-term soil moisture observations.
- **Potential for assimilation** of soil moisture information from in-situ stations.
- Future steps will be focused on validating timeseries of map pixels to soil moisture timeseries from Kansas Mesonet stations.