Higher-Resolution Soil Moisture for Hydrological and Agricultural Applications in the United States

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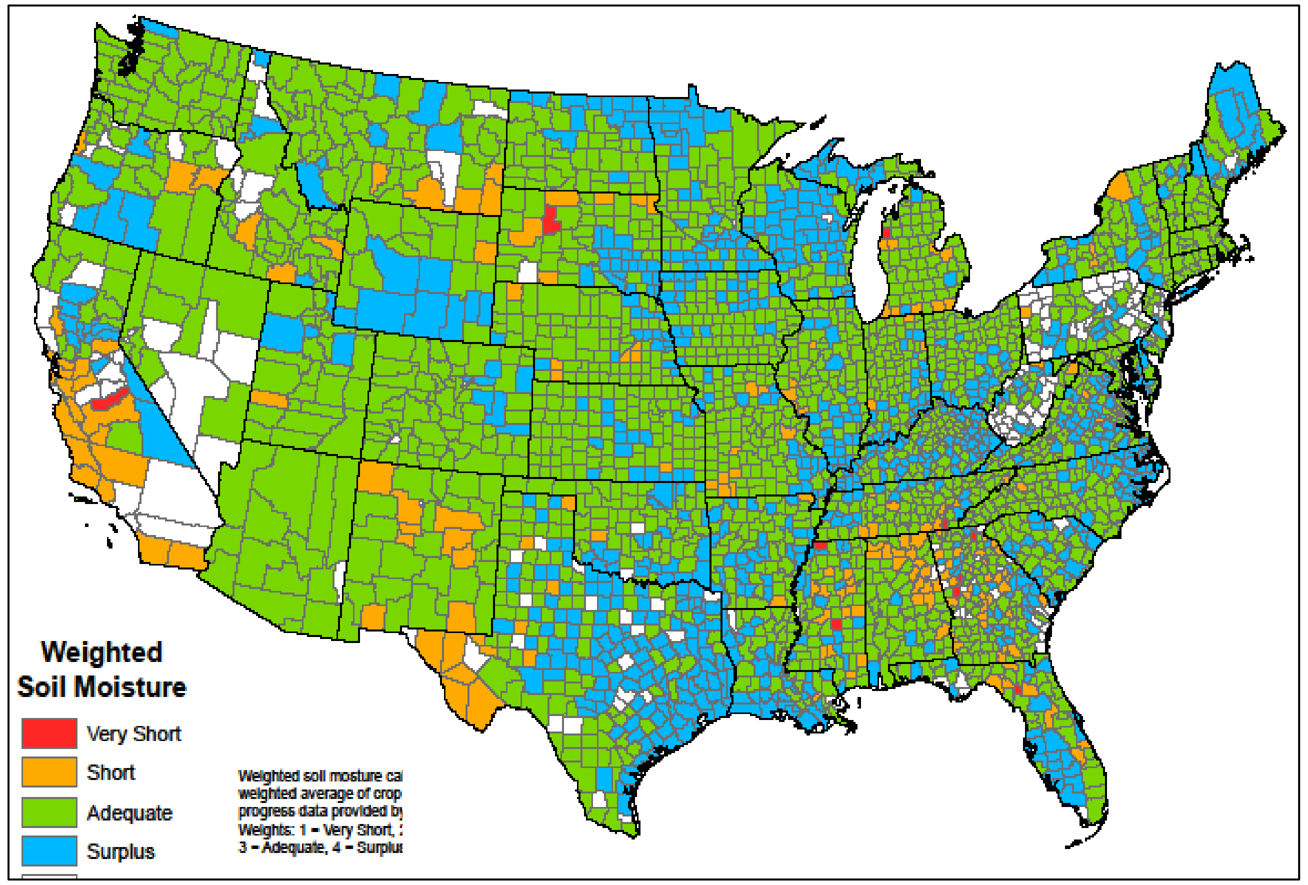
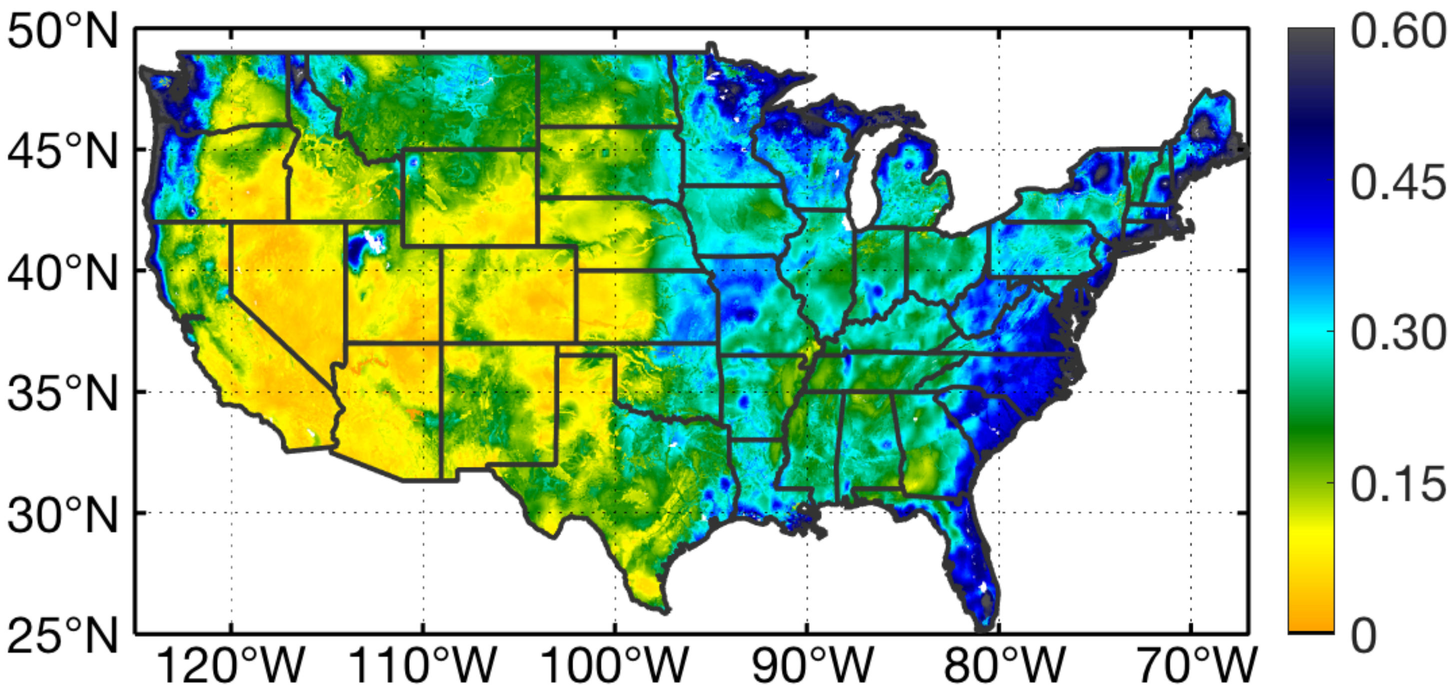
Project Goals

- **Project Goal:**

To develop and ingest high spatio-temporal soil moisture at 1 km resolution with 2-3 days revisit for USDA Crop Condition and Soil Moisture Analytics (Crop-CASMA) system

- **Project Motivation:**
  - USDA NASS currently uses **weekly surveys** that provide **qualitative** soil moisture at **county scale**
  - Remote sensing offers **more frequent quantitative** estimates at **high resolution** (1 km)
    - Improvement of the soil moisture assessments at field scale (1 km)
    - Remote sensing can provide soil moisture at greater temporal repeat (2-3 days)
  - Improvement of crop yield forecasts and assessments by incorporating the high resolution soil moisture into the USDA NASS Crop-CASMA system.

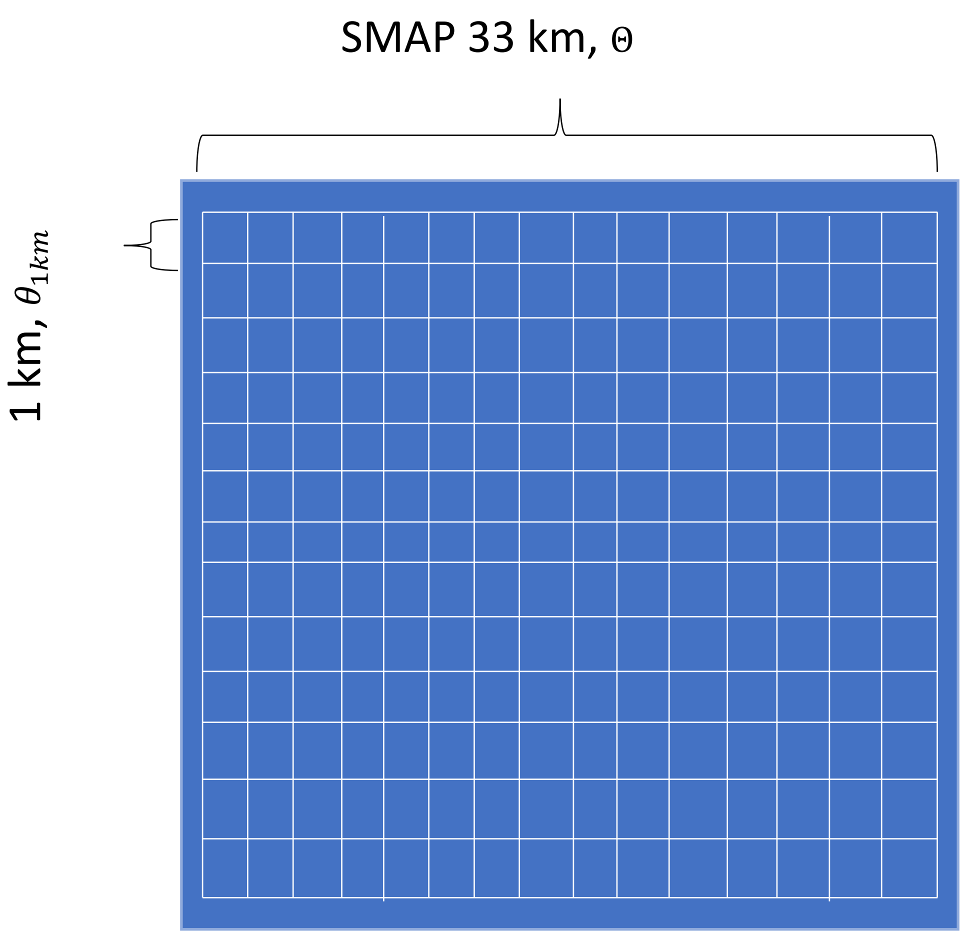




Disaggregated SM at 1km.

Methodology

- **Thermal Inertia Approach**
  - Wetter soil has lower heat transport on the surface and smaller temperature dynamics.
  - $\sigma^{T}_{\theta,1km} = f(\Delta LST_{MODIS}, NDVI_{MODIS})$
  - Noncoincident satellite revisits and cloud cover result in missing data or gaps in the product.
- **Soil Texture Approach**
  - $\sigma^{S}_{\theta,1km} = f(\Theta_{SMAP}, Soil\ hydraulic\ parameters)$
  - Model function was derived from Genichten-Mualem model and hydraulic parameters were from soil texture using pedotransfer equations.
- **Thermal Hydraulic disaggregation of Soil Moisture (THySM)**
  - During strong heat transport conditions the impact from thermal inertia is weighted higher; while soil texture approach is weighted higher when soil is wet based upon field capacity.



$$\theta^{HY}_{1km} = \theta^{T}_{1km} \cdot \frac{w_T}{w_T + w_S} + \theta^{S}_{1km} \cdot \frac{w_S}{w_T + w_S}$$

$$w_T = \frac{LH+SH}{max(Net\ Rad)};\quad w_S = \frac{\theta^{S}_{1km}}{FC}$$

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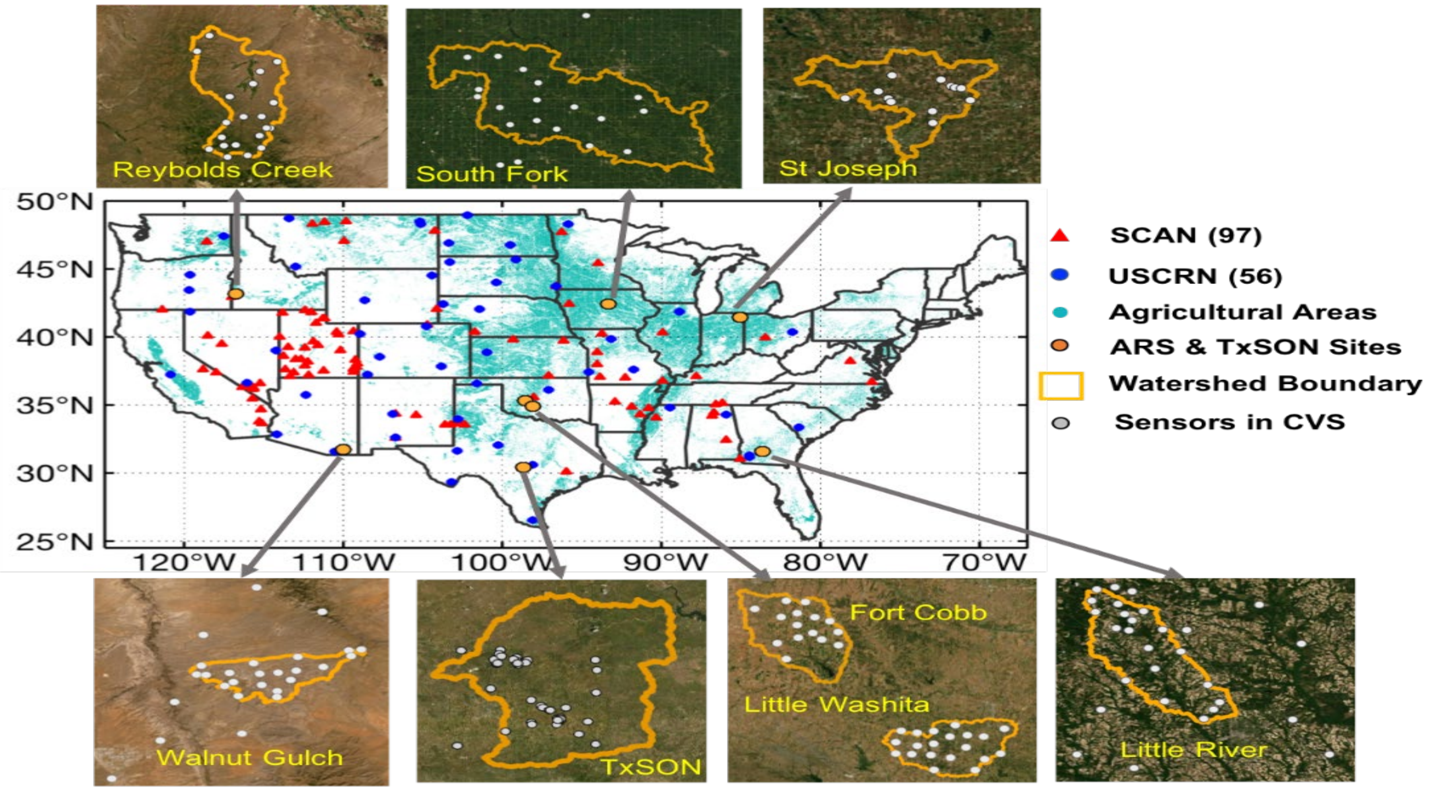
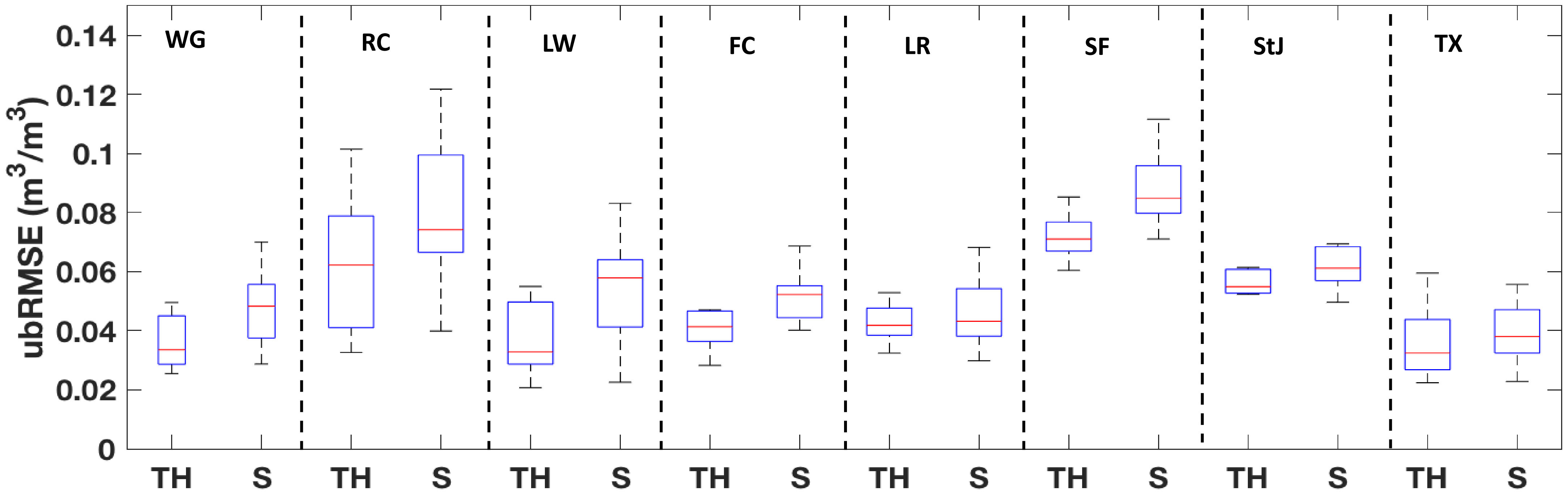
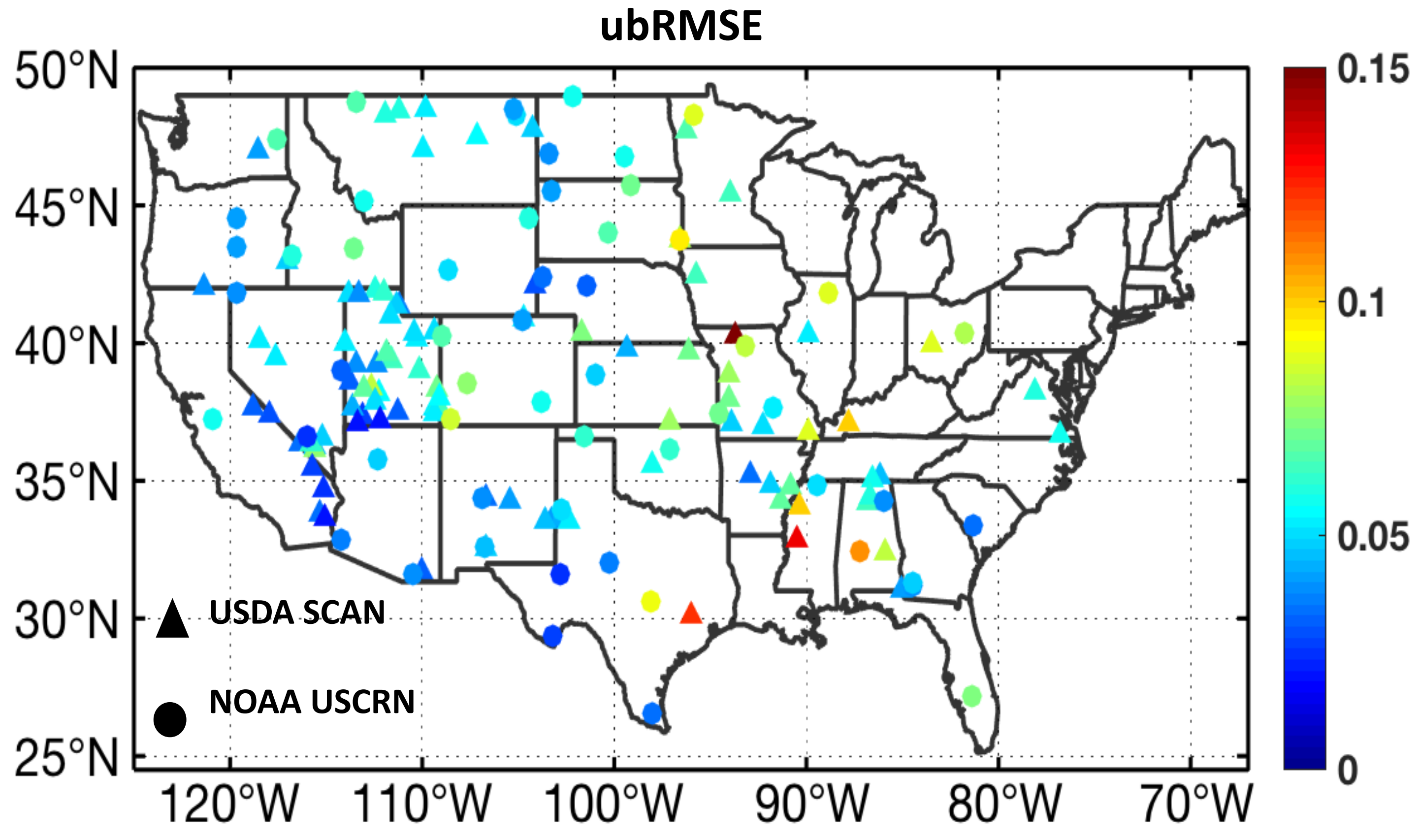
High Resolution Soil Moisture - Validation





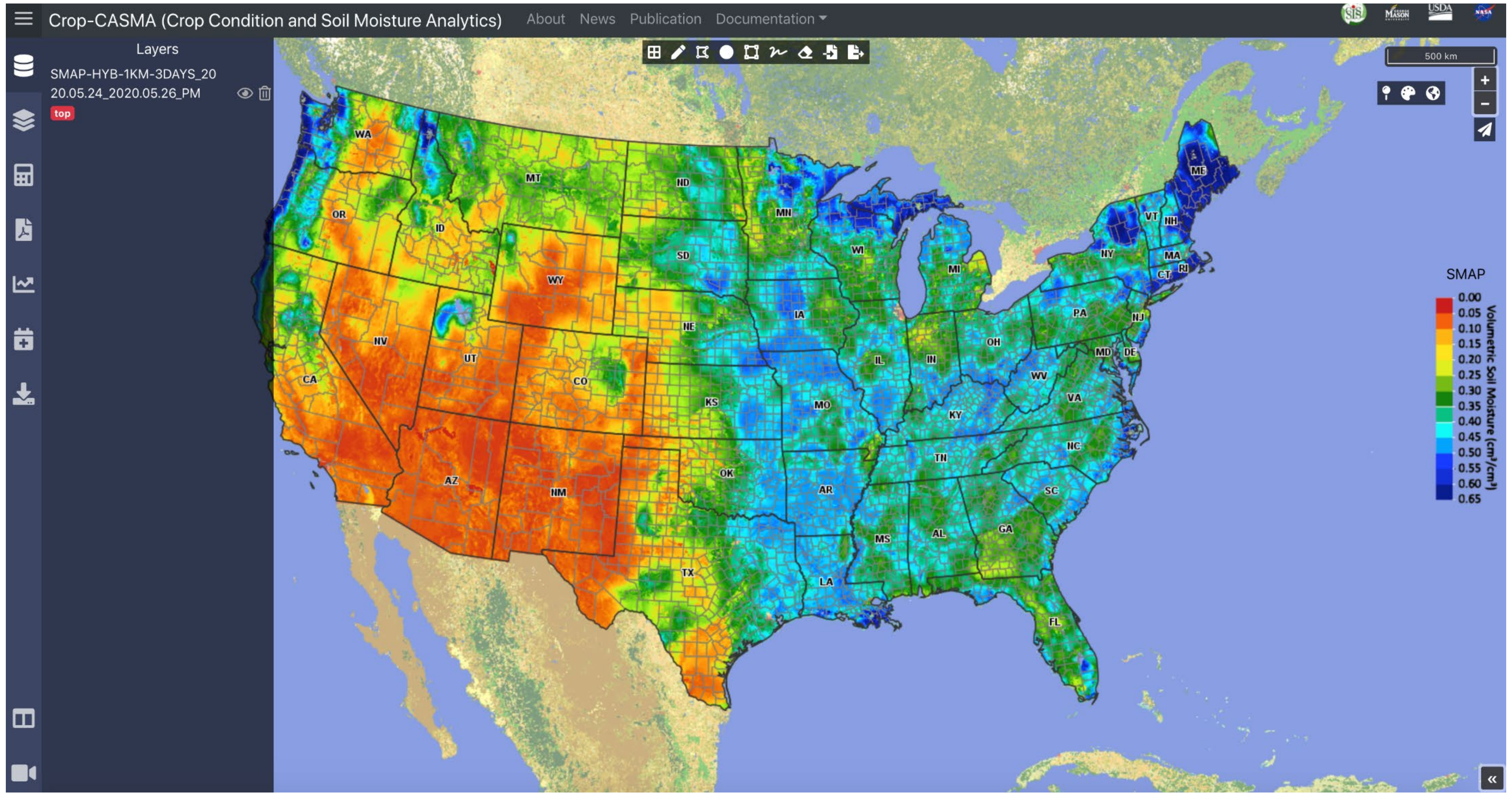


Assessment using observations from 04/01/2015-03/31/2019

	SMAP Enhanced (33 km)*				SMAP/Sentinel1 (1 km)				THySM (1 km)			
	ubRMSE	RMSE	Bias	R	ubRMSE	RMSE	Bias	R	ubRMSE	RMSE	Bias	R
Walnut Gulch	0.026	0.030	0.015	0.80	0.047	0.067	0.035	0.56	0.036	0.051	0.025	0.62
Reynolds Creek	0.040	0.042	-0.013	0.65	0.086	0.115	-0.026	0.56	0.064	0.086	-0.026	0.69
Little Washita	0.021	0.028	-0.018	0.91	0.054	0.087	-0.017	0.64	0.038	0.063	-0.007	0.79
Fort Cobb	0.029	0.055	-0.047	0.88	0.052	0.086	-0.021	0.68	0.042	0.079	-0.028	0.69
Little River	0.036	0.069	0.059	0.78	0.046	0.123	0.112	0.65	0.044	0.128	0.119	0.71
South Fork	0.052	0.064	-0.038	0.71	0.087	0.112	-0.057	0.49	0.072	0.099	-0.057	0.53
Saint Joseph's	-	-	-	-	0.061	0.086	0.021	0.59	0.057	0.082	0.014	0.64
TxSON	0.021	0.023	-0.008	0.93	0.041	0.070	-0.026	0.74	0.037	0.067	-0.013	0.84
Overall	**0.032**	**0.044**	**-0.007**	**0.81**	**0.059**	**0.093**	**0.003**	**0.61**	**0.049**	**0.082**	**0.003**	**0.69**

Assessment of THySM

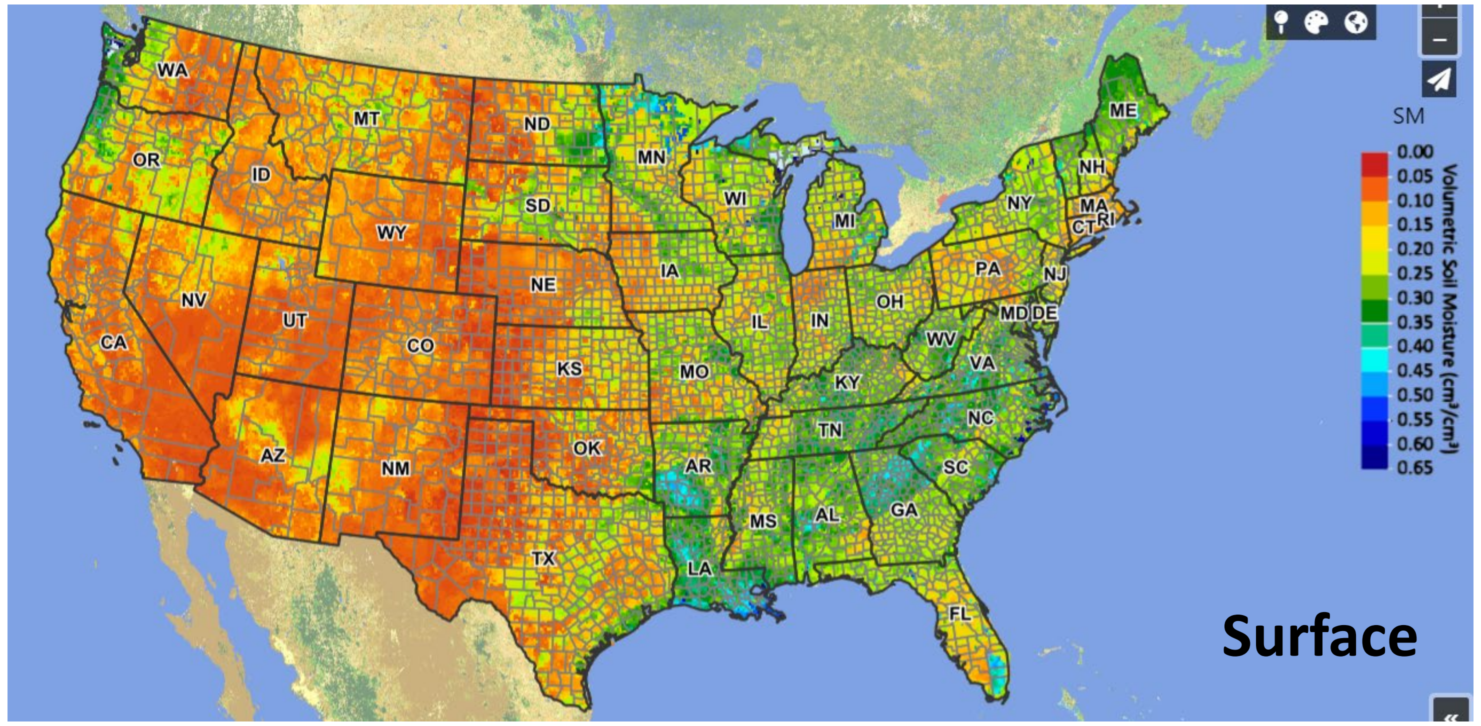
- THySM is developed by disaggregating SMAP in the CONUS domain at a spatial resolution of 1 km.
- ThySM has been evaluated using *in situ* measurements from 7 SMAP core validation sites (dense network) and 153 stations of USDA SCAN and NOAA CRN (sparse network).
- Overall, unRMSE of THySM is **0.048** m^3/m^3.
- THySM is ingested into NASS's Crop Condition and Soil Moisture Analytics (Crop-CASMA) system.
- Data available at https://portal.nccs.nasa.gov/datashare/thysm/THYSM_PM_DAILY/

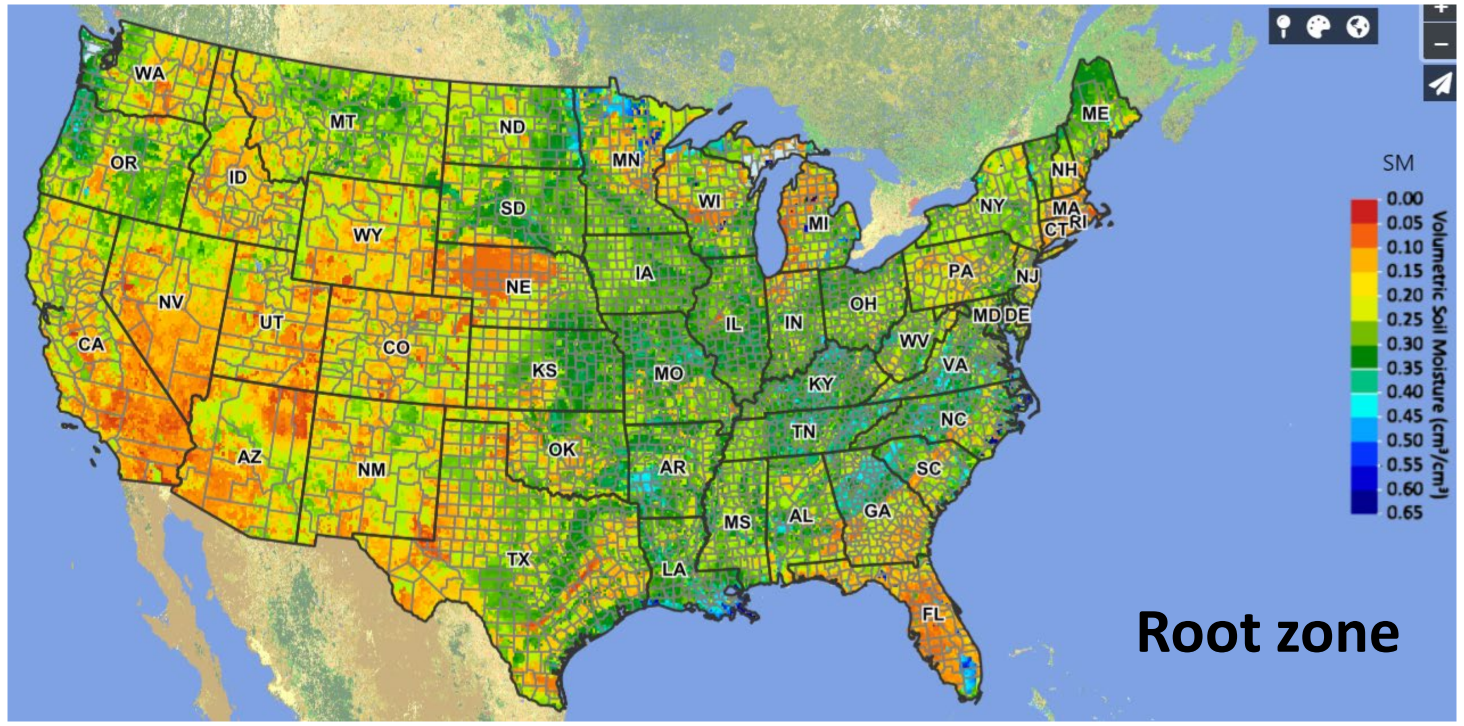


Liu *et al.,* 2022. Thermal hydraulic disaggregation of SMAP soil moisture over continental United States. *IEEE JSTARS*. Vol. 15, pp. 4072-4093.
Zhang *et al.,* (2022). Crop-CASMA: A web geoprocessing and map service based architecture and implementation for serving soil moisture and crop vegetation condition data over U.S. croplands. *Int. J. of Appl. Earth Observ. & Geoinfo*. Vol. 112, pp. 102902.

Crop-CASMA Soil Moisture data products

- Soil moisture data
  - SMAP 9 km original data, aggregated daily, weekly top and rootzone soil moisture data
  - High resolution 1 km daily, weekly topsoil moisture data
  - 1 km & 9km daily, weekly top and rootzone soil moisture anomaly data
  - Weekly 1 km topsoil & 9 km top and rootzone categorical soil moisture condition data





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High Resolution Soil Moisture for USDA

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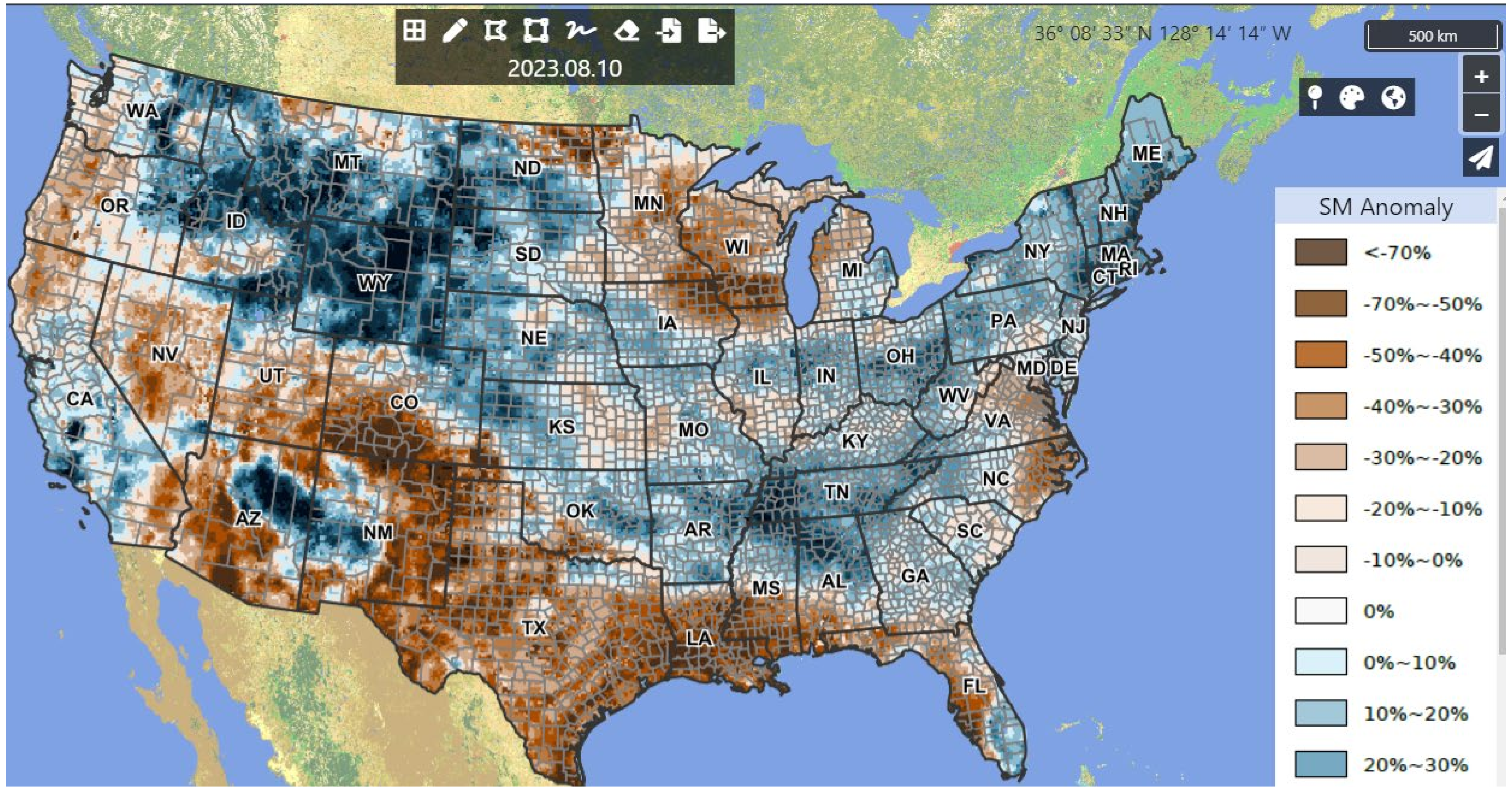
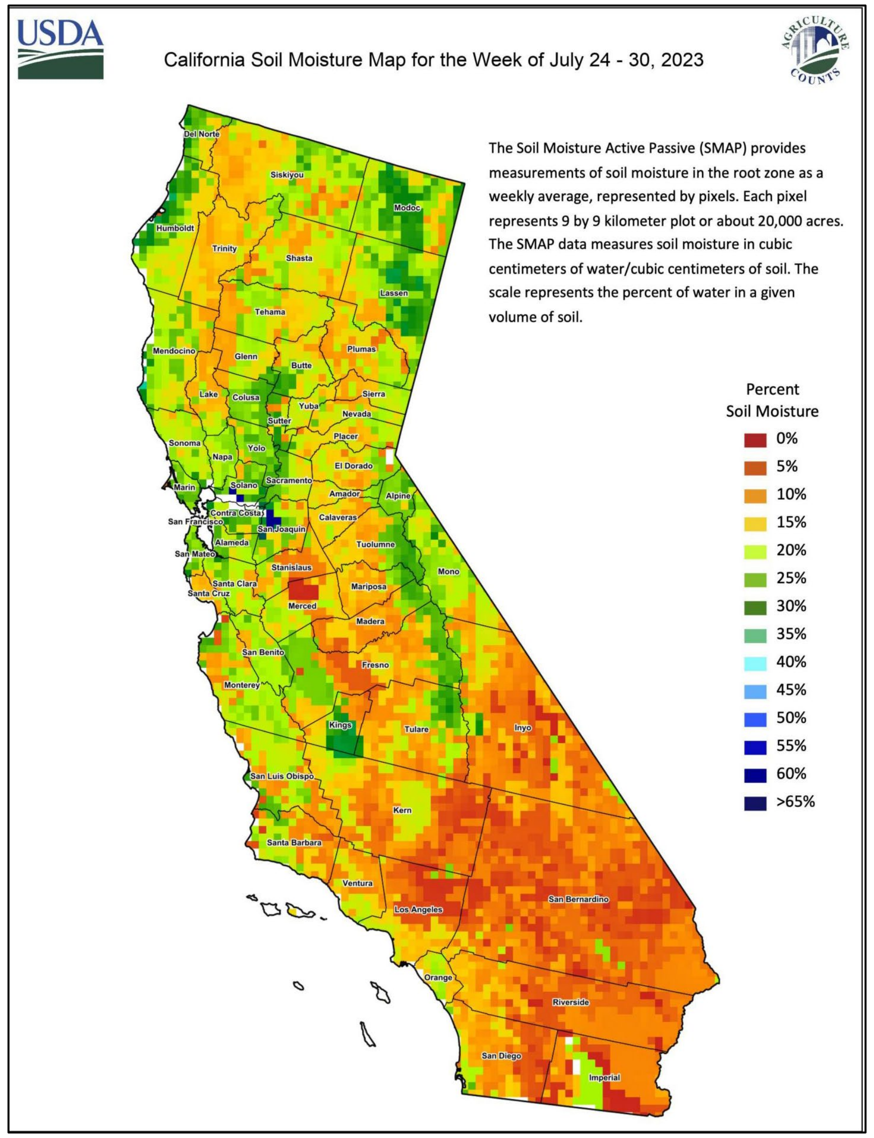
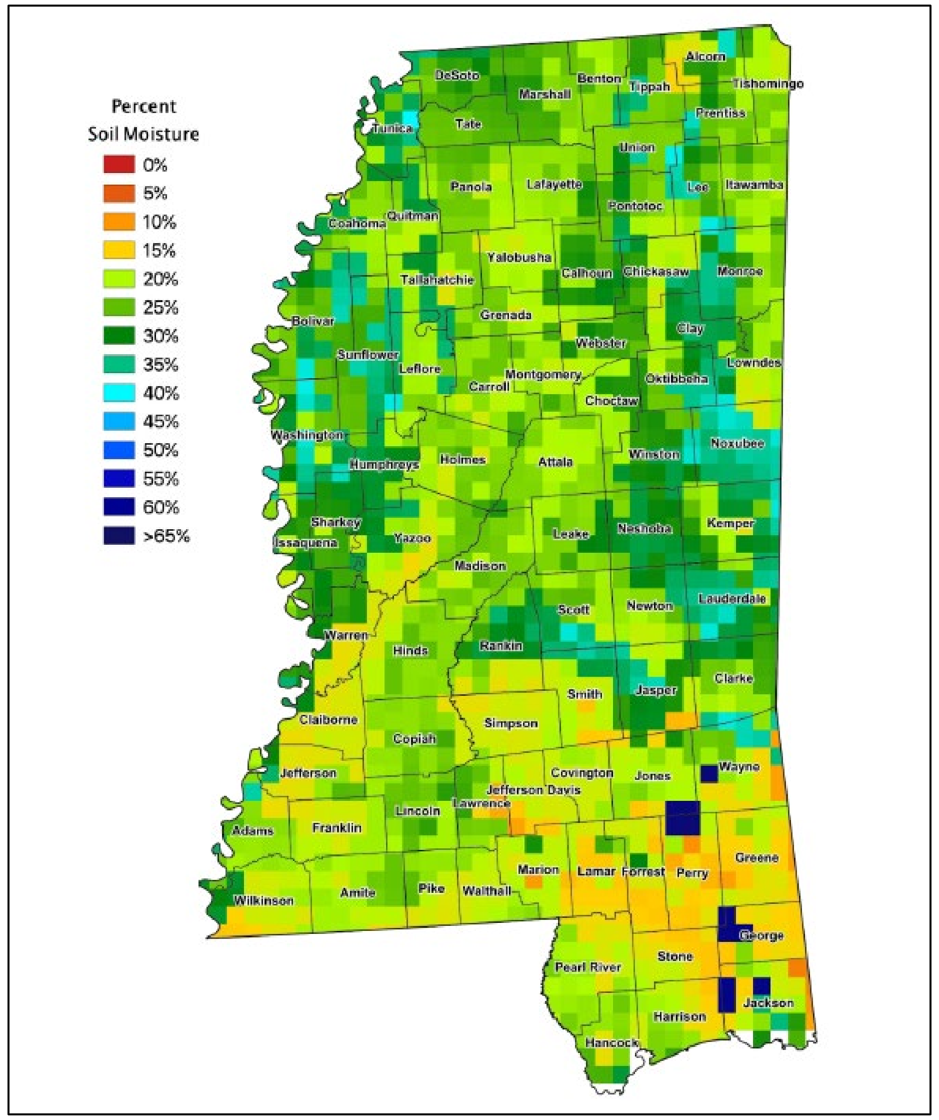
USDA Crop-CASMA System







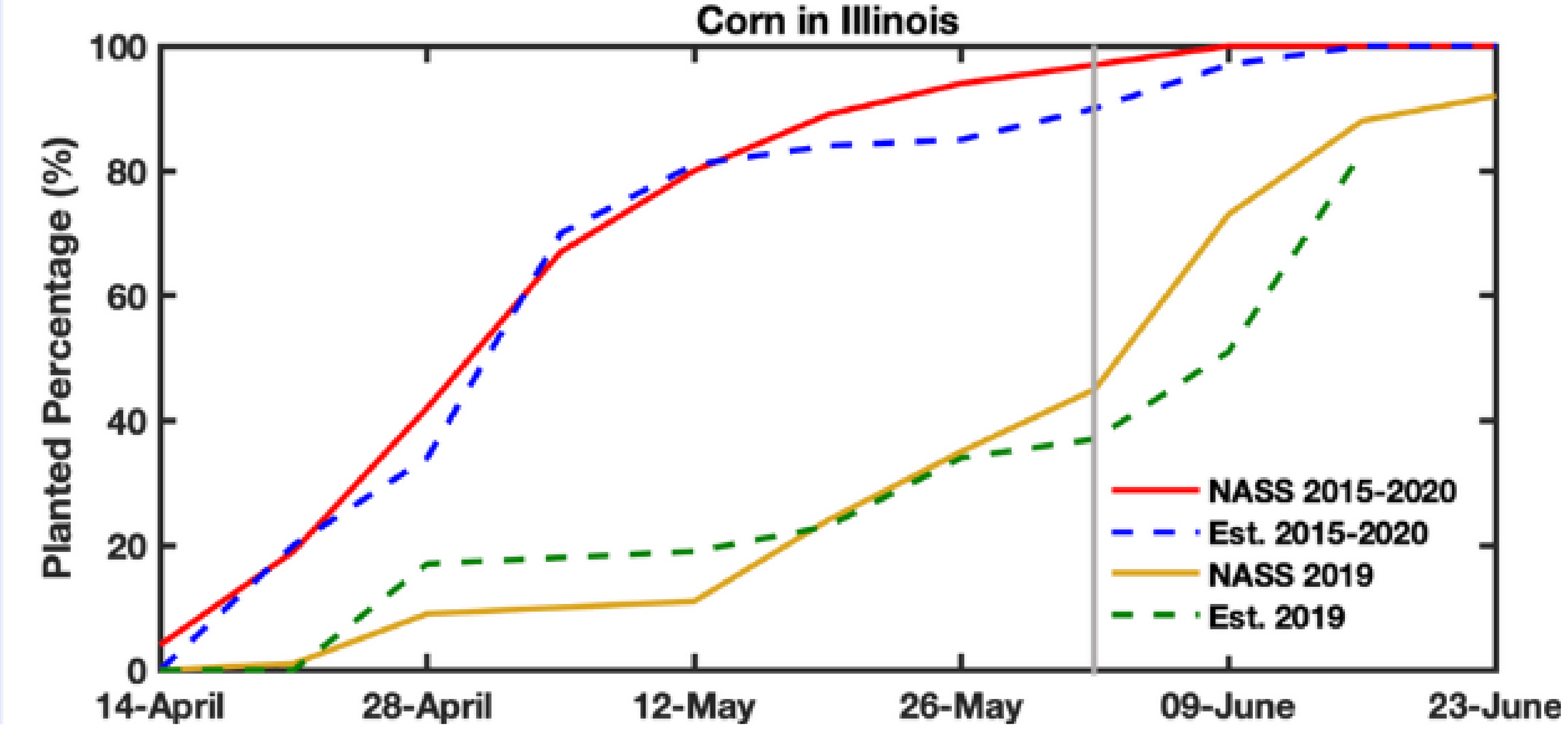
Soil Moisture Anomaly map for CONUS (8/10/2023) and soil moisture maps for CA and MS.

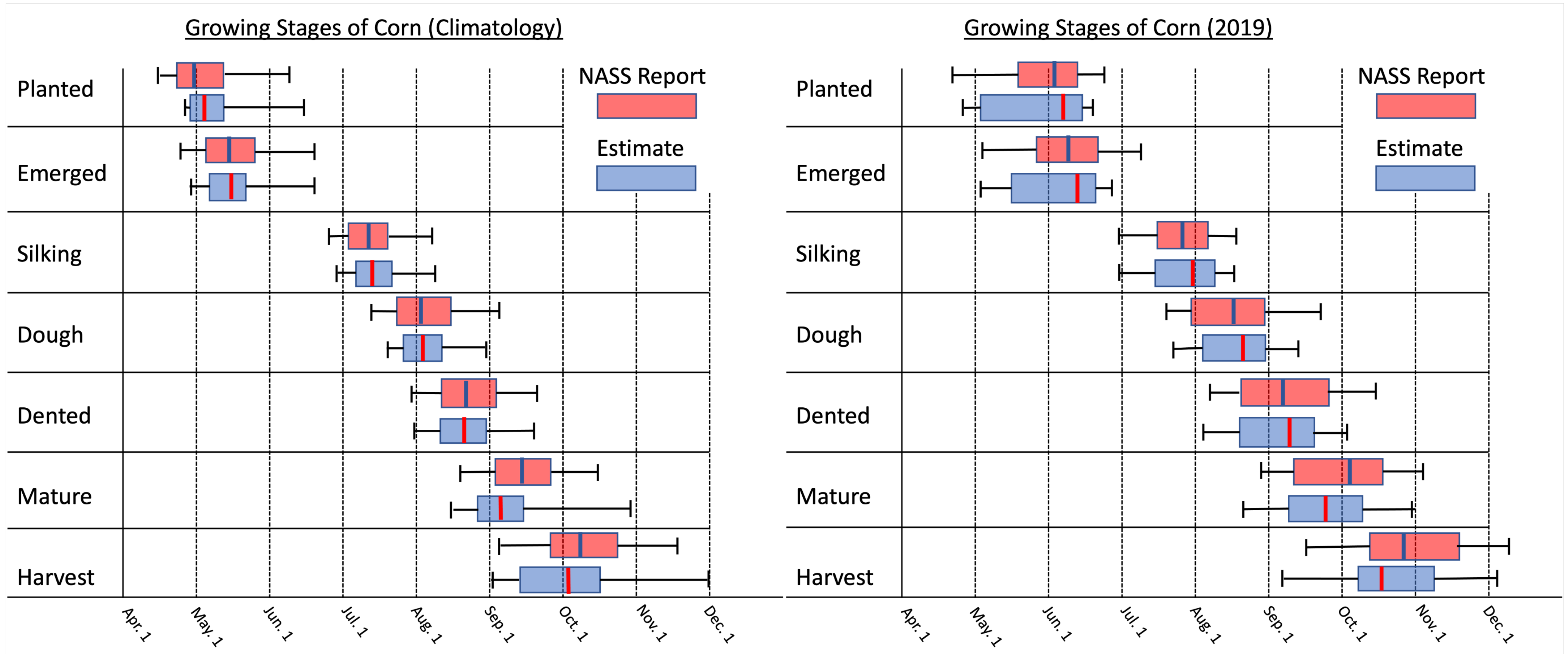
High resolution soil moisture product has been implemented for agricultural applications by USDA.

- More than 50% water is used for agricultural purposes in Western states
- Operationally used by USDA NASS for their weekly reports on agricultural conditions for improved decision making (https://cloud.csiss.gmu.edu/Crop-CASMA/).
- SMAP soil moisture was operationally ingested by USDA demonstrating the value of NASA remote sensing observations for societal benefit
- Project was funded by WWAO/Applied science program; operational data use continues.

Planting Date and Corn Growth Stages

Estimation of Corn Phenology





- $33 billion loss to agriculture sector due to 2019 floods over mid-west US
- Corn planting date determined based on soil moisture, temperature and soil trafficability
- Corn phenology was estimated using GDD based on estimated planting date.
- In the figure, horizontal bar charts show the earliest and latest dates of the growth stage, and when 20, 50, and 80 percentiles of agricultural pixels reach the GDD requirements.
- Relatively delayed growth at every stage by 20-30 days in 2019 as compared to climatology.
- Overall, the estimated phenology timelines agree with NASS survey reports for climatology and 2019 with RMSDs of 4.5 and 5.6 days, respectively.

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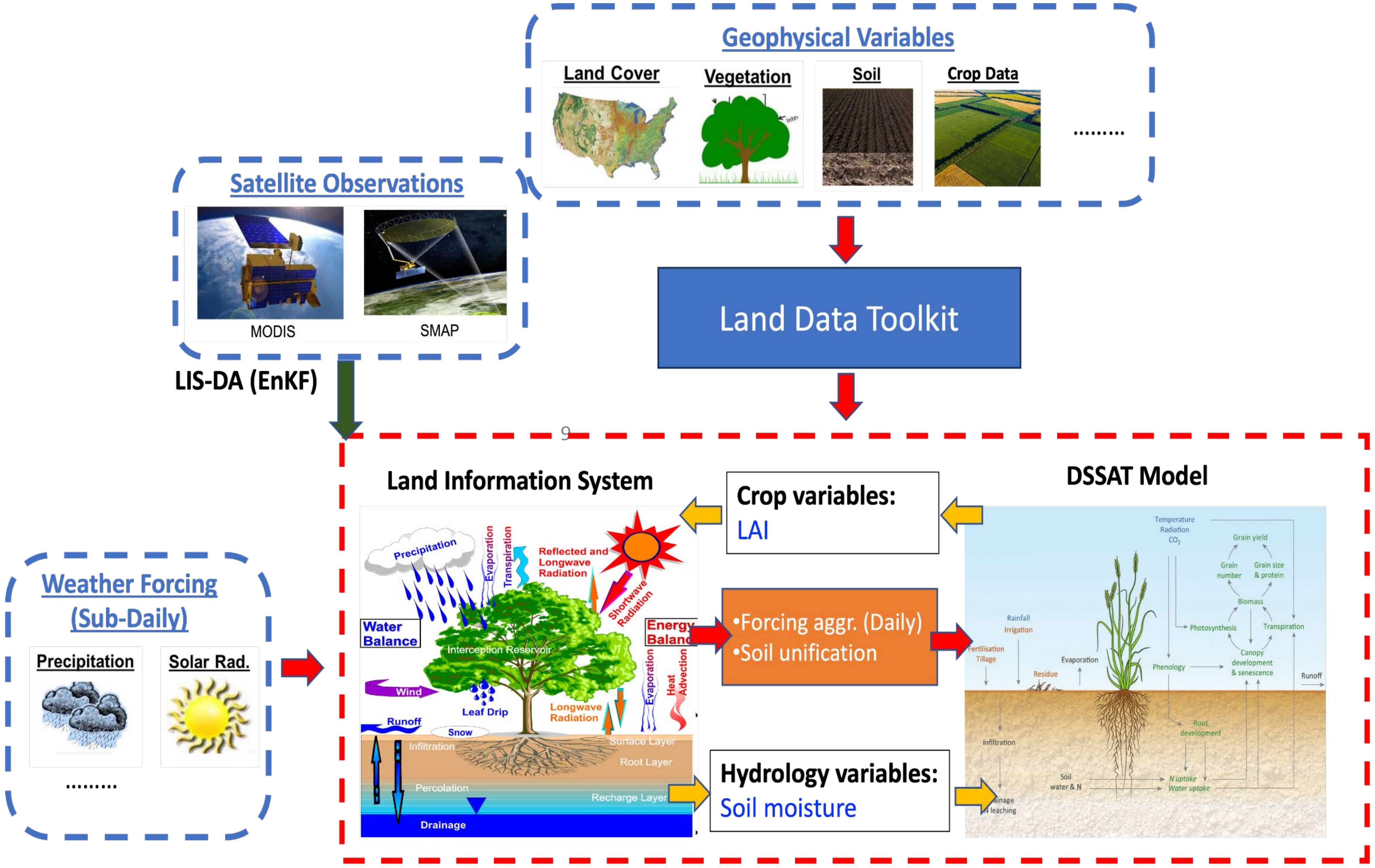
High Resolution Hydrology and Crop Information System

- **Leverage complementarities of state-of-the-art hydrology and crop models for crop yield simulation and predictions, and for scenario studies.**
- Hydrology models lack crop growth models; Crop model lack stat-of-the-art hydrology
- First ever implementation of a process-oriented coupled hydrology and crop model
- Develop an Land-Agriculture Information System (LAIS) that leverages complementarities of hydrology and agriculture models (LIS and DSSAT).
  - Built upon NASA's Land Information System (LIS), the framework is capable of assimilating our high-resolution soil moisture published on Crop-CASMA and other satellite-based soil moisture observations.
  - Collaborative project between NASA Goddard, GISS, and USDA NASS funded by ESTO AIST program.



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Impact of Soil Moisture on Agriculture

- Simulated crop yields for corn and soybean follow soil moisture conditions, indicating high sensitivity of soil moisture to crop yields.
- The developed LAIS provides a system for studying impacts of various weather/soil conditions on agriculture.