Mapping Real-Time Root Zone Soil Moisture Using Satellite and Soil Data with AI Methods

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Background

- Understanding the dynamics of profile Soil Moisture (SM) dynamics is essential for a wide range of applications in earth and environmental sciences.
- Current passive microwave remote sensors operating at L-band, such as Soil Moisture Active Passive (SMAP), are limited to sensing surface soil moisture and offer only coarse spatial resolution, rendering them inadequate for detailed small- and medium-scale applications, including agriculture and landscape-scale modeling.

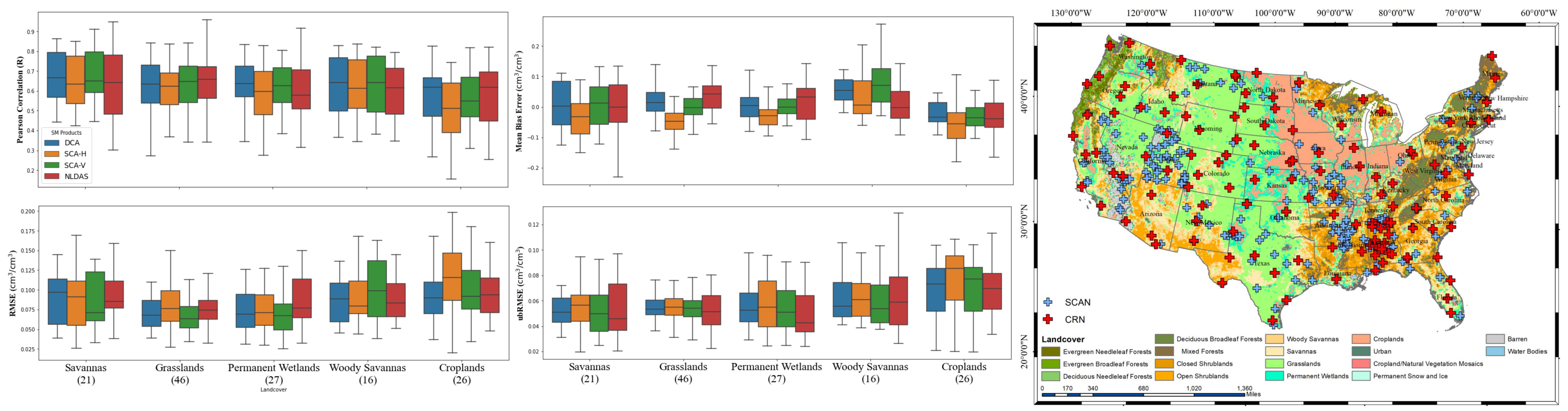
Objective

- To integrate long-term SMAP satellite soil moisture observations, Natural Resources Conservation Service (NRCS) Soil Properties of US (SOLUS100) soil physical properties, climatic, and MODIS optical satellite data to estimate soil moisture at multiple soil depths using a Convolutional Neural Network (CNN) – Long Short-Term Memory (LSTM) deep learning model.

Methodology

Large-Scale Soil Moisture and Deep Learning Modeling

- To develop and evaluate the ConvLSTM2D model, we used Soil Climate Analysis Network (SCAN) and Climate References Network (CRN) soil moisture stations across the CONUS, providing soil moisture at five depths (5, 10, 20, 50, and 100 cm) and for different land cover types.



Architecture of Deep Learning Network & Training

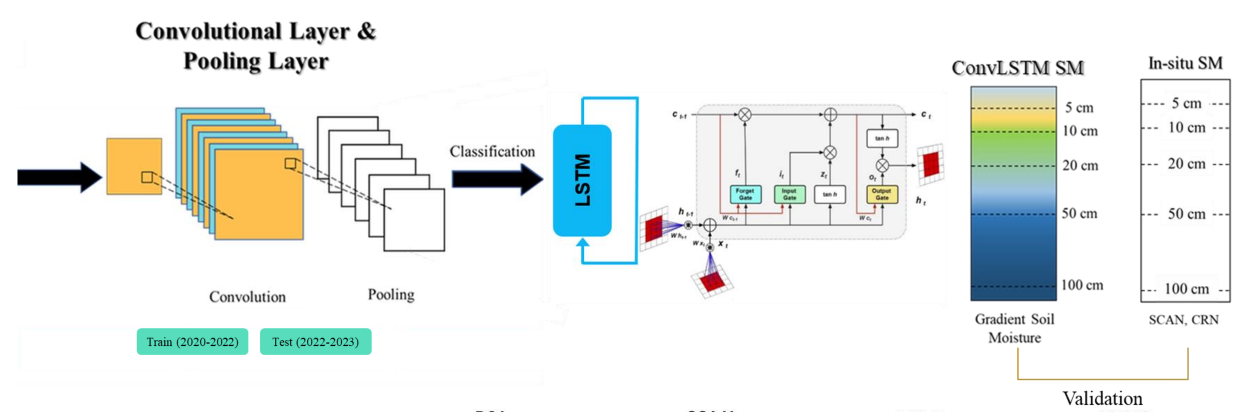
- The NLDAS soil moisture data were integrated with SMAP DCA (dual channel algorithm) surface soil moisture (5 cm) to produce new products with the highest correlation and lowest error.

Inputs (Training):
SMAP L3 (SMPE) (9-km) Auxiliary Data:
- Polarized (H & V) Brightness Temperature
- Vegetation Scattering Albedo
- Surface Roughness Parameter
- Effective Soil Temperature
- Vegetation Water Content

SOLUS100
- Soil Bulk Density
- Sand & Clay content

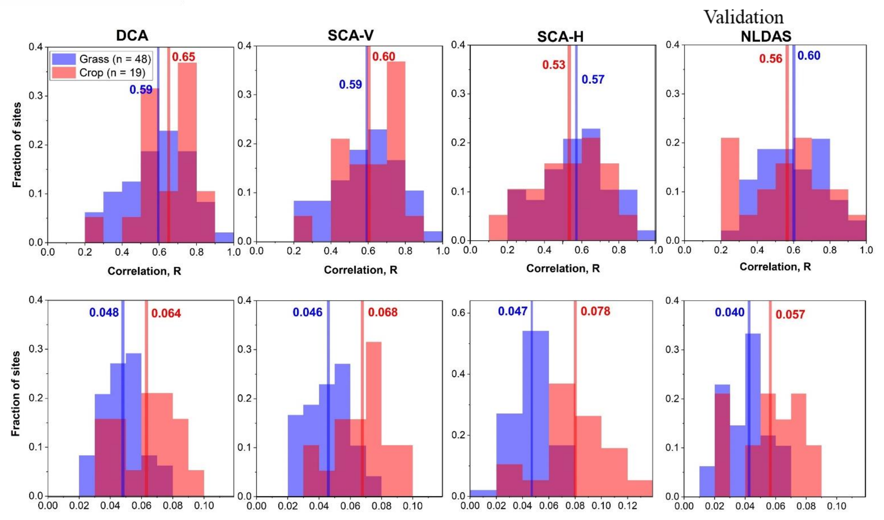
Topography data:
- Digital Elevation Model (DEM)
- Curvature
- Aspect
- Flow Direction
- Slope

Satellite/Model:
- MODIS (SWIR)
- Precipitation (GPM)
- NLDAS 2



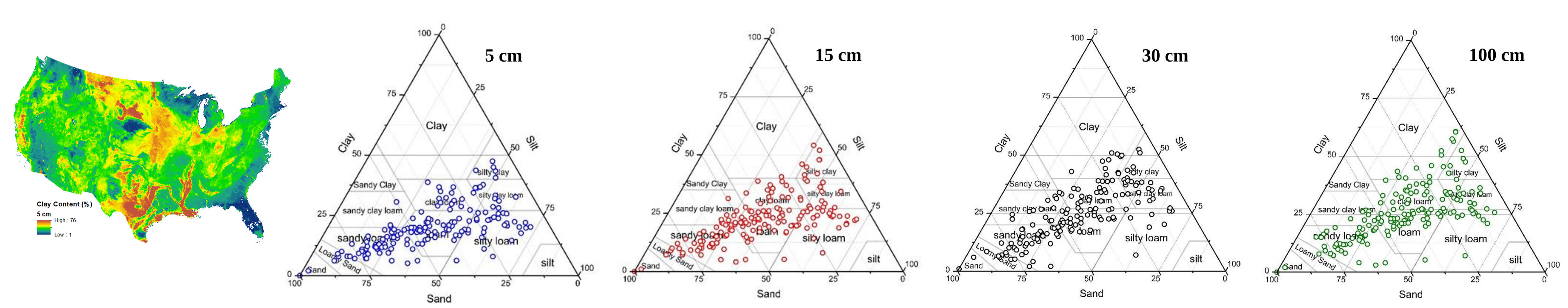
Constriction of Benchmark Data

- A new soil moisture product (0-5 cm), with minimum bias and maximum Pearson correlation based on in-situ SCAN and CRN measurements, was produced for grasslands and croplands in the U.S. using the integration of NLDAS and SMAP SM (SCA, DCA) products.
- The integrated SM product exhibits superior performance (higher R and lower ubRMSE) over SMAP products (based on in-situ SCAN and CRN measurements) across grasslands and croplands.
- The new product was used to train a ConvLSTM2D model (years 2020 to 2022). The results were tested vs in-situ SCAN and CRN soil moisture data (year 2022).



Soil Physical Properties Maps (SOLUS100)

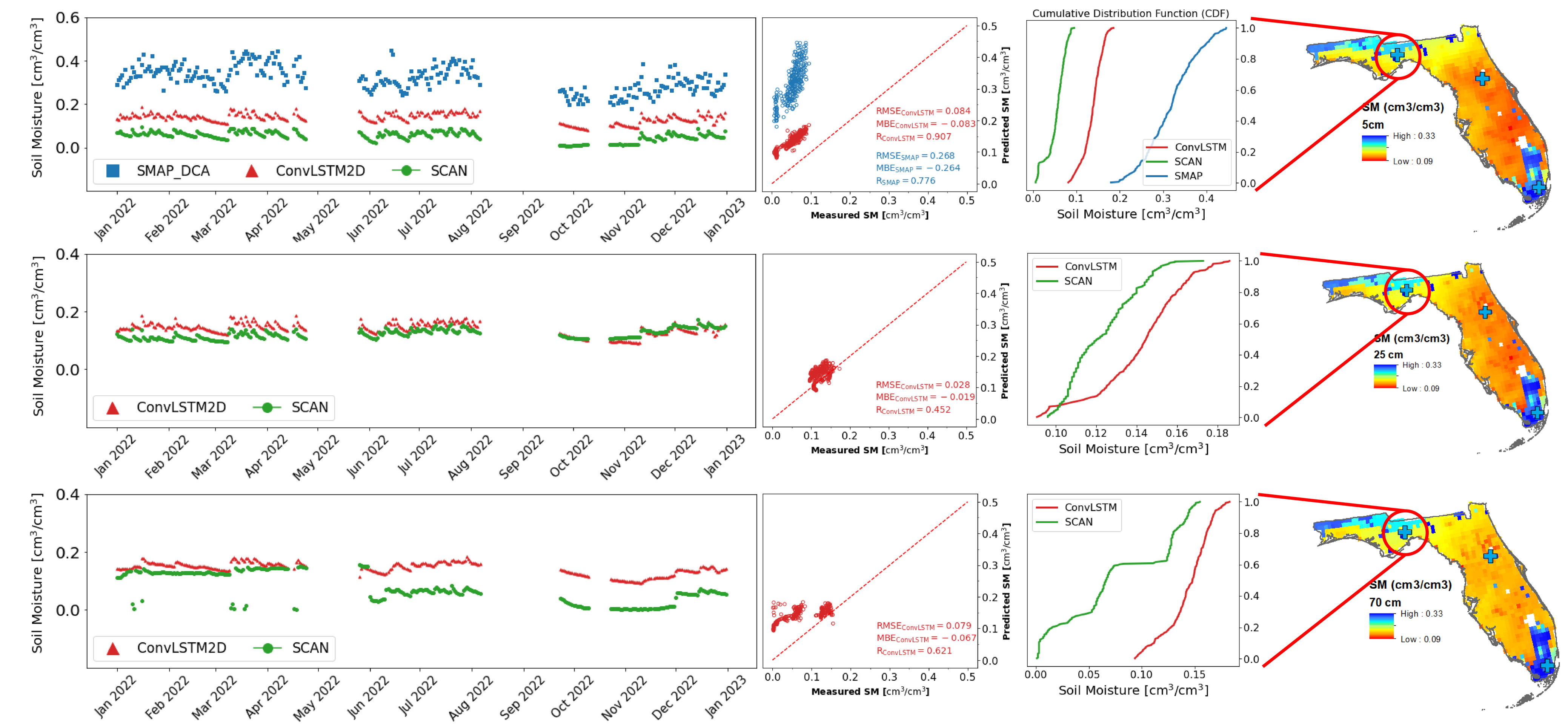
- NRCS's SOLUS100 soil physical properties raster maps (100 m resolution) for clay, sand, silt, and bulk density content at multiple soil depths were used. The soil texture across SCAN soil moisture stations is highly variable, ranging from sand to clay.



Results

Estimating Soil Moisture in Florida

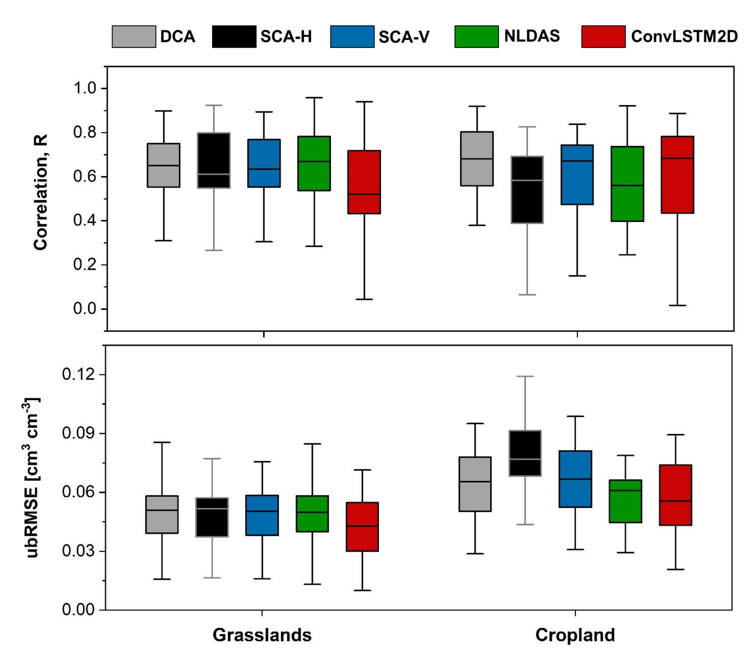
- The soil in Florida is characterized by its sandy texture, leading to rapid drying after rainfall event, a feature that SMAP soil moisture products may not effectively detect.
- The developed ConvLSTM model offers superior predictions compared to the SMAP product, as it benefits from incorporating the NLDAS product, which is grounded in land surface modeling.
- Sometimes the in-depth sensors at SCAN sites malfunction. When this occurs, the affected data are either eliminated from the dataset or substituted with readings from a proximate depth, such as 50 cm or 100 cm, in place of the 70 cm depth measurements.
- To enhance the assessment of the model's effectiveness in Florida, it is necessary to augment the soil moisture data through the utilization of local soil moisture monitoring networks.

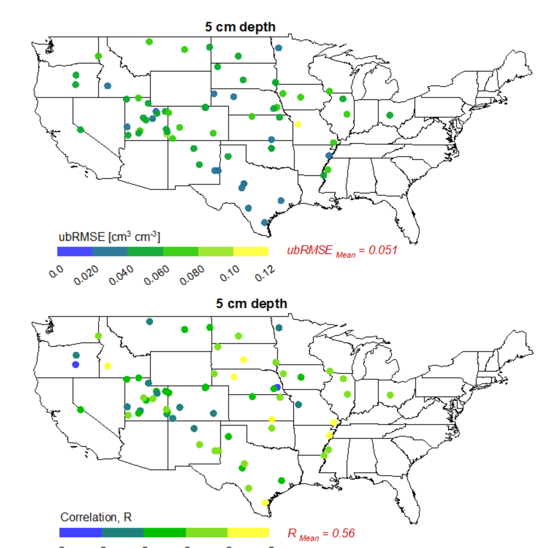


Large-Scale Soil Moisture Estimation

Surface (5-cm) Soil Moisture Estimates and Evaluation

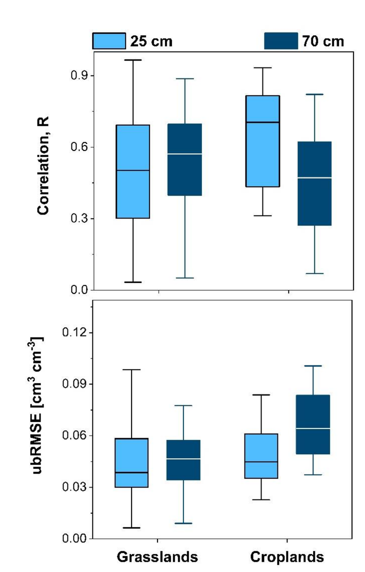
- The CNN-based SM estimates (testing set) slightly outperformed the existing SMAP SM products, particularly in cropland areas, as indicated by R and ubRMSE values.

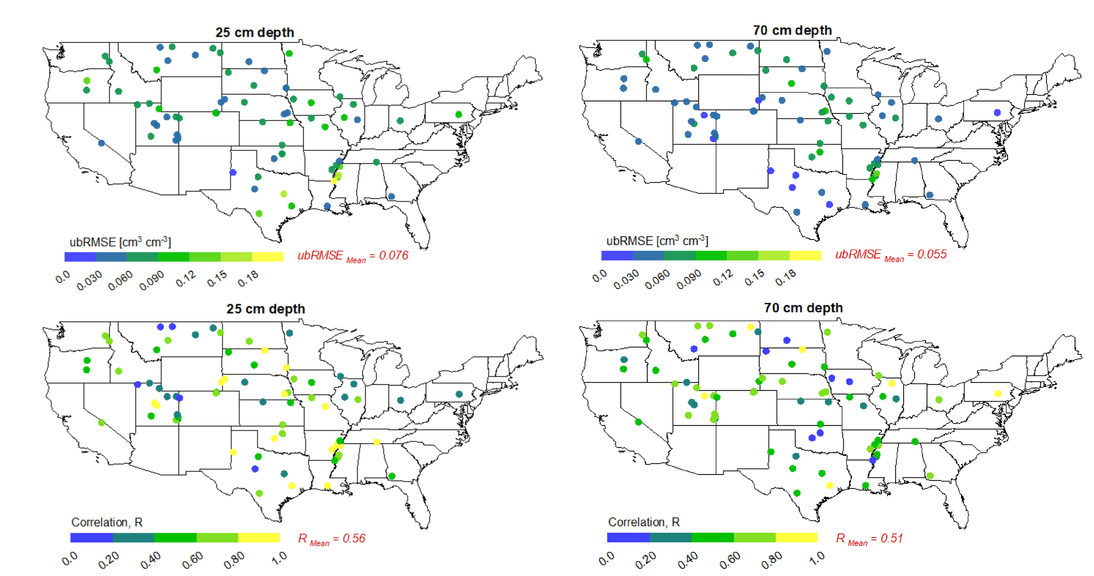




Profile Soil Moisture Estimates and Evaluation

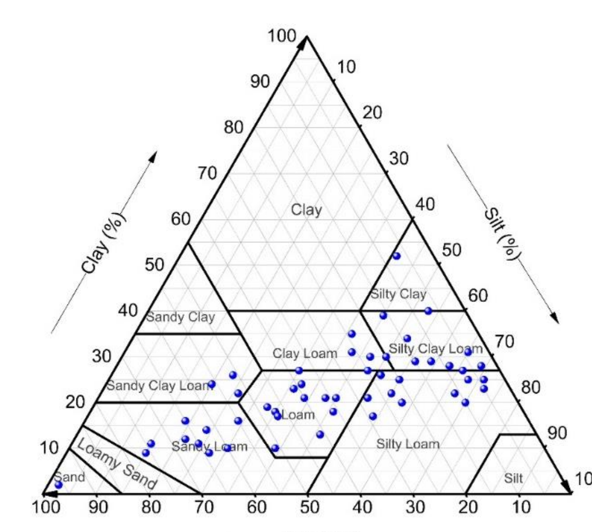
- The preliminary results, the DL model can accurately estimate the profile SM across grasslands and croplands.
- The accuracy of SM estimates is observed to be higher at 25 cm depth compared to that at 70 cm.



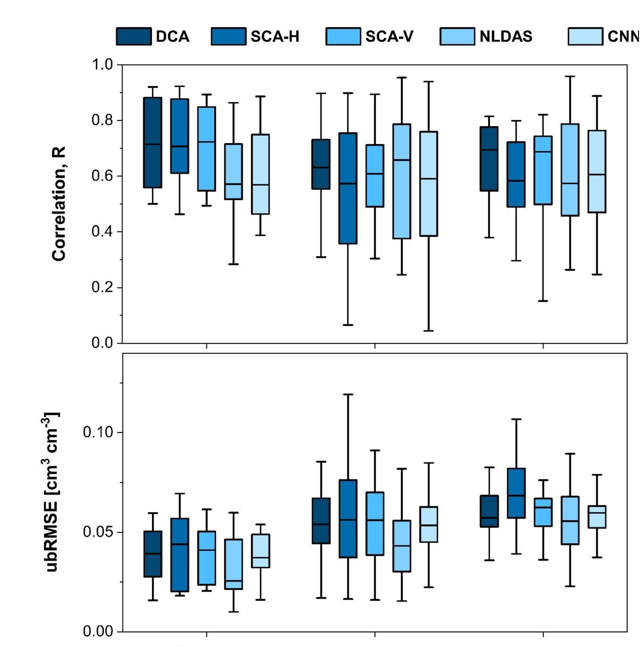


Effects of Soil Texture

- The most accurate estimates were obtained for coarse-textured soils, followed by medium- and fine-textured soils.
- The DL model demonstrated the ability to produce high-quality surface SM estimates, surpassing other SMAP SM products in terms of ubRMSE values across various soil textural classes.



Sand Sandy Loam	Coarse Text.
Loam Sandy Clay Loam Silt Loam	Medium Tex.
Slay Loam Silty Clay Silty Clay Loam	Fine Tex.



Conclusions and Next Steps

- At large-scale, the ConvLSTM model, when trained with SMAP brightness temperature (L3) and other auxiliary datasets, performed well in estimating both surface and sub-surface SM in croplands and grasslands.
- Our next step involves: (1) evaluating the potential of ConvLSTM model to produce high-spatial resolution surface and root zone soil moisture in Florida using AI- based downscaling algorithms; (2) developing ConvLSTM models for nowcasting and forecasting surface and subsurface soil moisture.

References

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[2] Colliander, A. et al. 2022. Validation of Soil Moisture Data products from the NASA SMAP mission. IEEE Journal of Selected Topics in Applied Observations and Remote Sensing. 15, 364-392.

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