Spatially-Varying Statistical Soil Moisture Profile Model by Coupling Memory and Forcing using Hydrologic Soil Groups to Estimate Vertical Soil Moisture Profile

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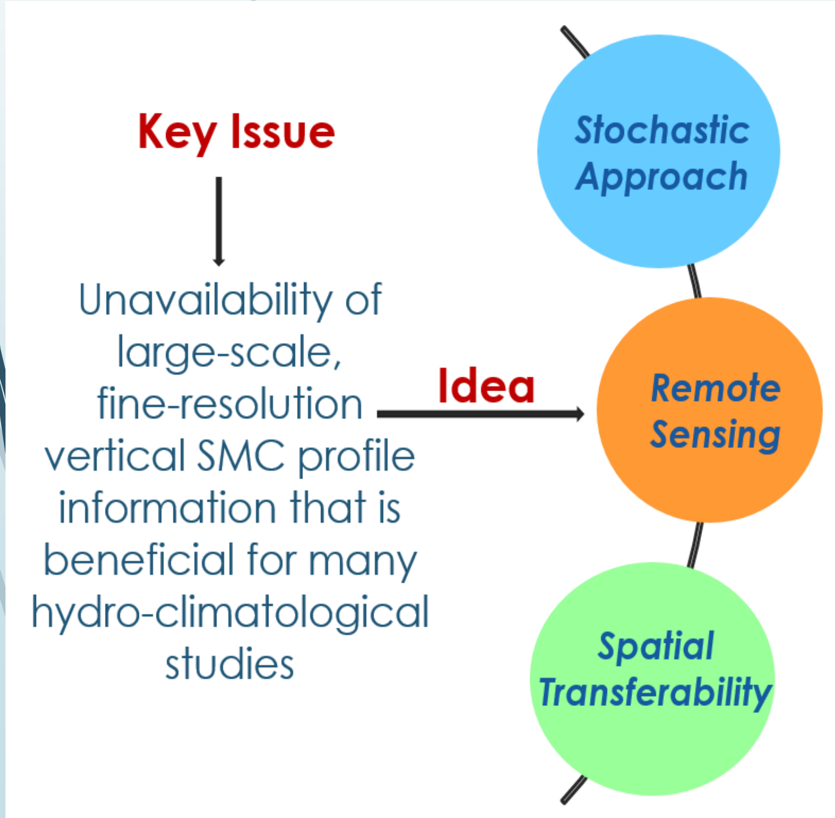
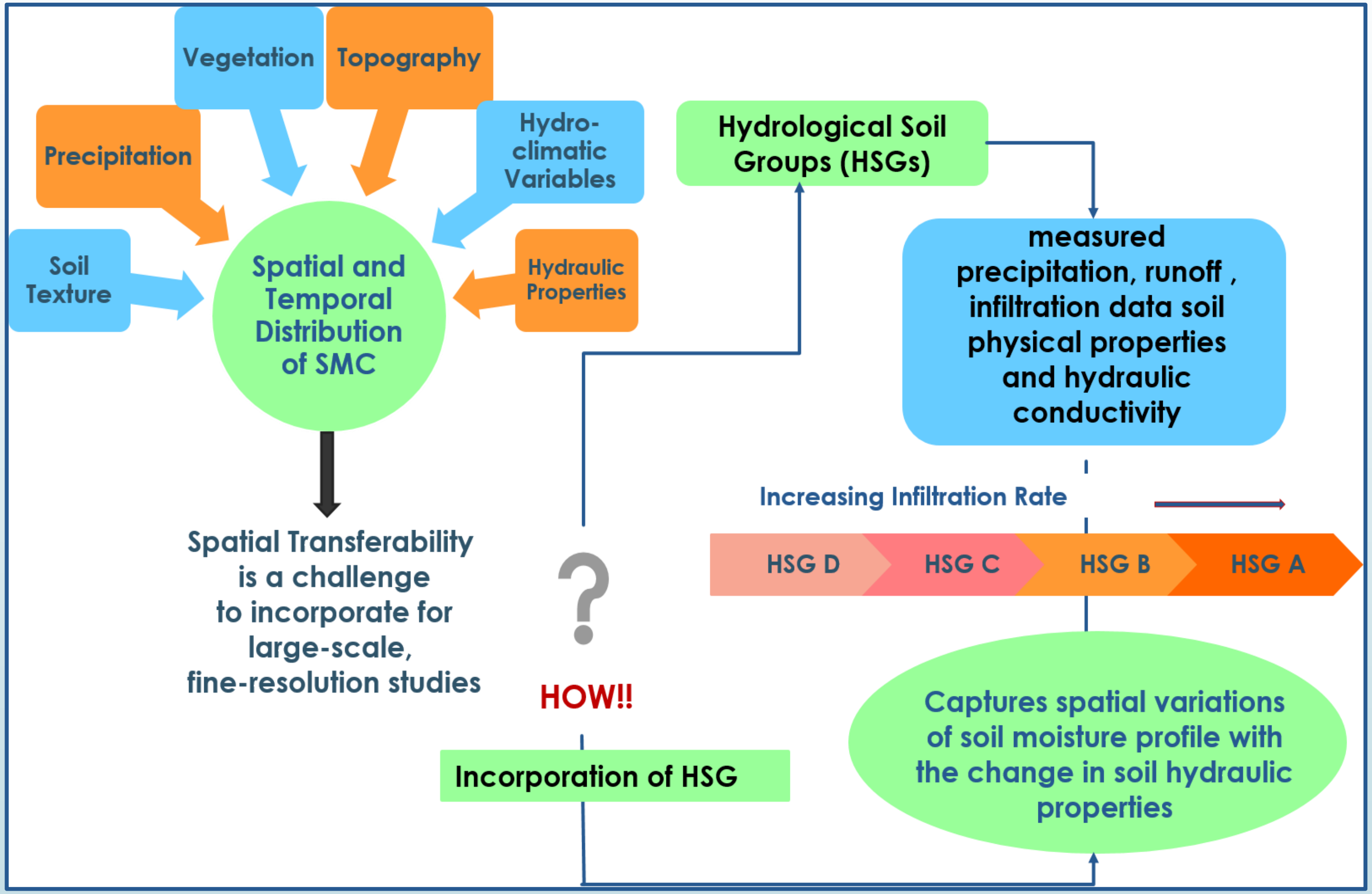
Introduction

Soil Moisture Content (SMC) of the unsaturated zone plays a significant role in determining the water and energy fluxes between soil and atmosphere.



Imparting Spatial Transferability

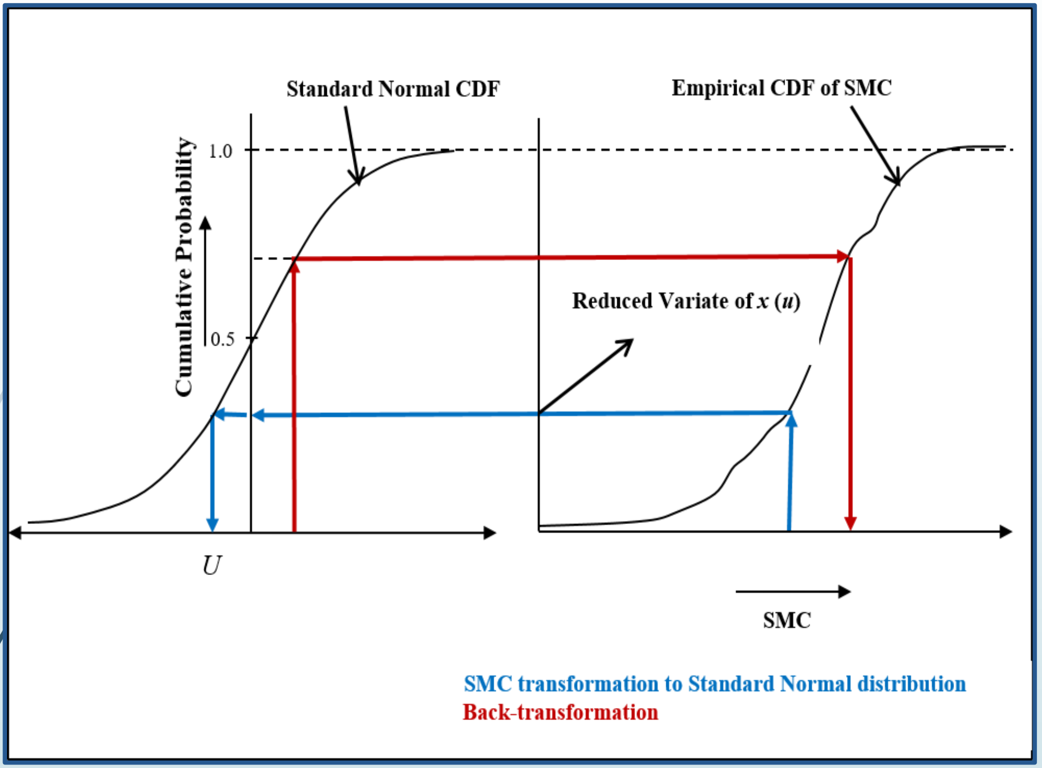


Data Source and Study Area

- The **daily soil moisture time series data** is obtained from the **International Soil Moisture Network (ISMN)** website (http://www.wcc.nrcs.usda.gov/ scan/) from **Soil Climate Analysis Network (SCAN), U.S. Climate Reference Network (USCRN) and SNOwpack TELemetry (SNOTEL)** networks.
- The **HSG** of each monitoring stations are determined from the **Web Soil Survey (WSS)** (https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm).
- SMC is collected from total **171 monitoring stations** from these three different networks for the **depths 5, 10, 20, 50 and 102 cm**.

Development of spatially varying Statistical Soil Moisture Profile (SSMP) Model by Coupling of Memory and Forcing

Data Transformation



Model with Spatial Transferability

All Model Developing Stations

HSG A	HSG B	HSG C	HSG D
21	28	33	21

HSG-specific SSMP models are developed for 5-10 cm, 10-20 cm, 20-51 cm and 51-102 cm depth pairs for each station

Median value of different HSG-specific SSMP models orders of all four depth pairs across all stations is the model order of that particular depth pair

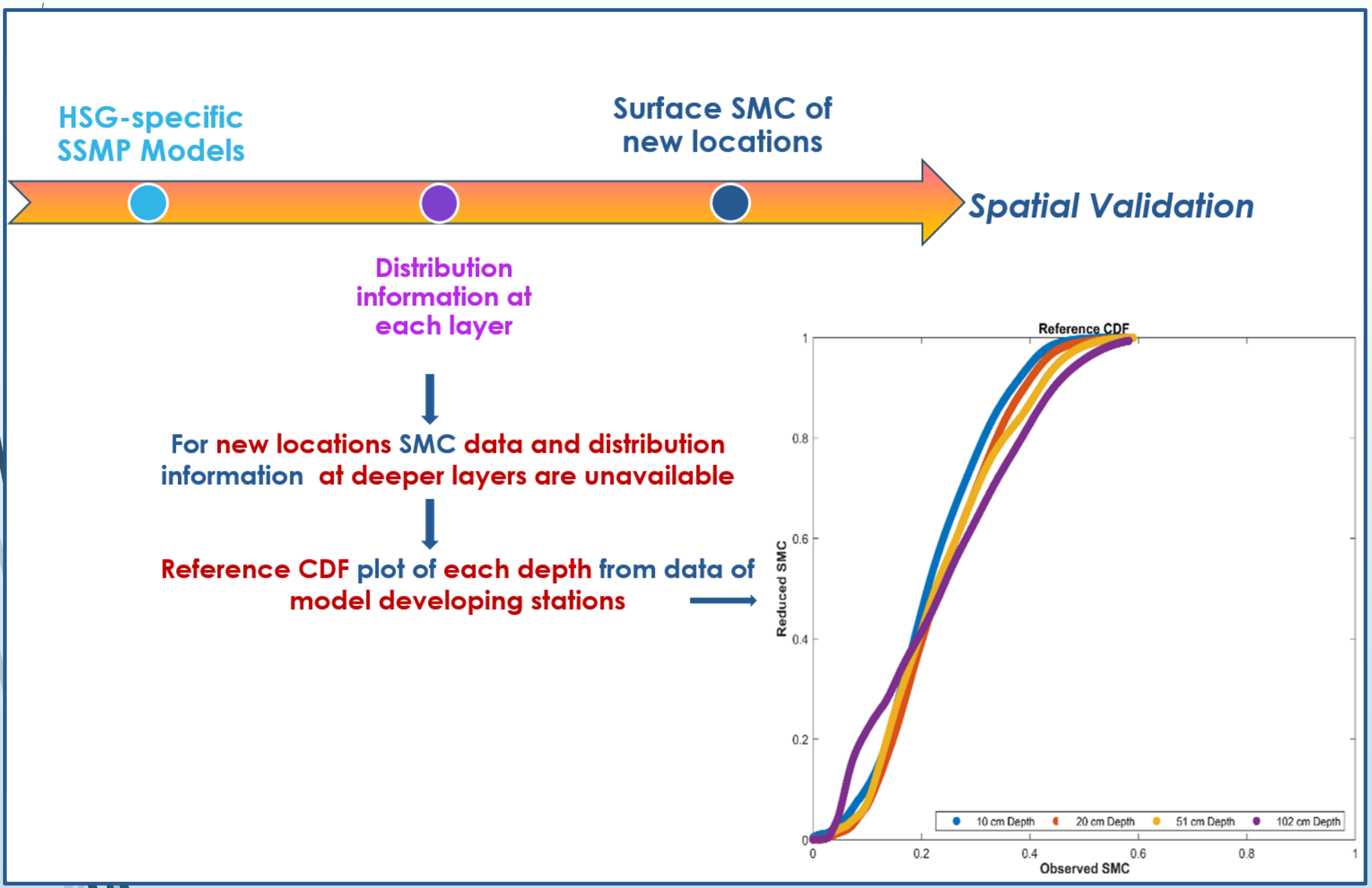
Mean of coefficients obtained with median model order corresponding to each depth pair across the stations is the HSG-specific coefficient for that particular depth pair

Model at a Location

$$SM_k(t) = \sum_{i=1}^{p} a_i SM_k(t-i) + \sum_{j=d}^{q+d-1} b_j SM_{k-1}(t-j) + e(t)$$

Memory Coefficient · Memory · Forcing Coefficient · Forcing

Spatial Validation of SSMP Model

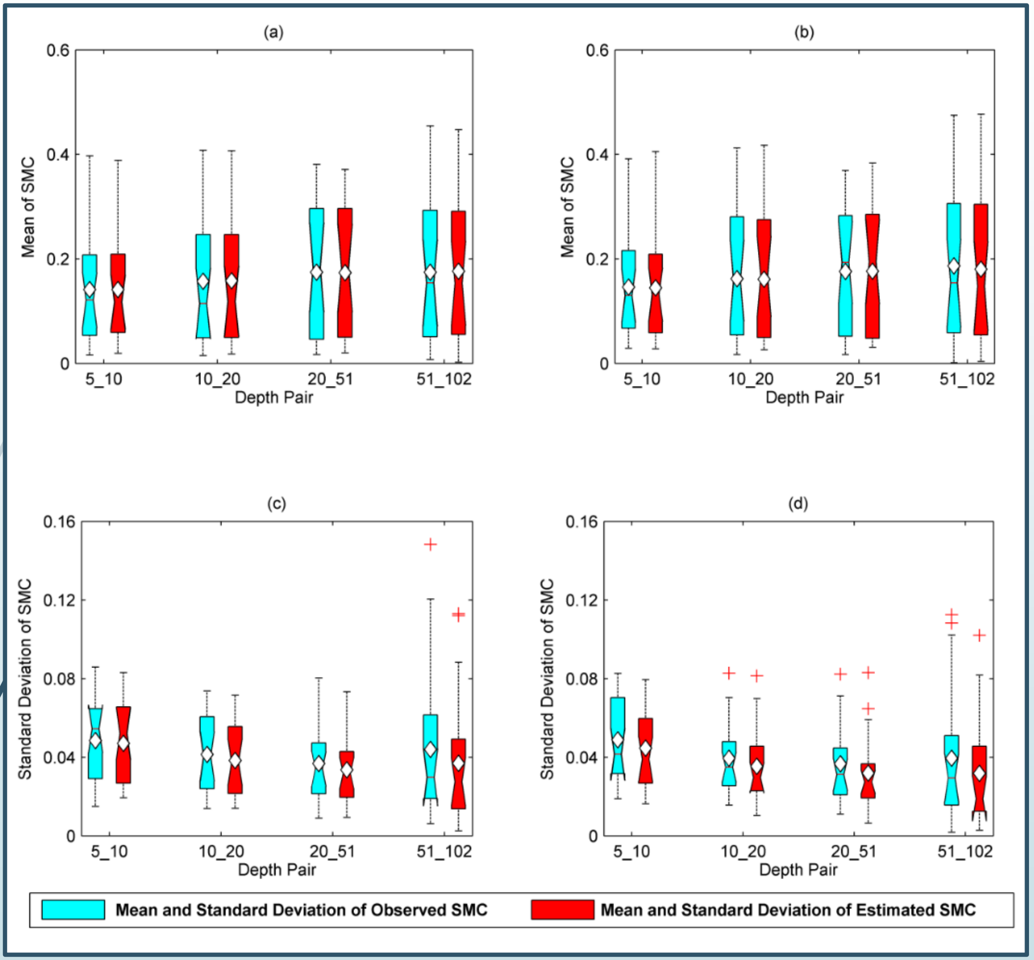


Numbers of stations for Spatial Validation from each HSG are : **HSG A-17; HSG B- 21; HSG C-17** and **HSG D-17**

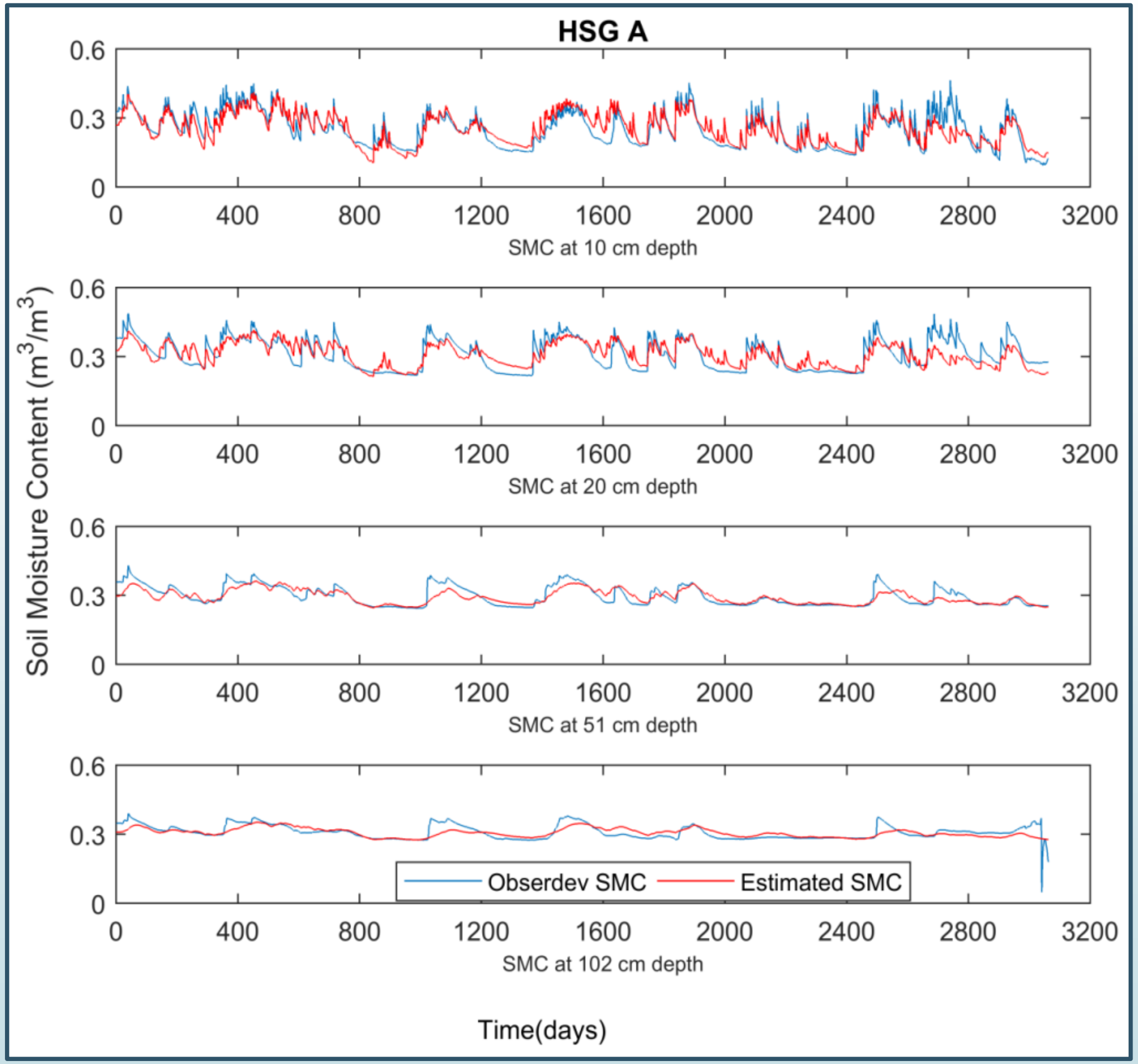
Correction for Deviation in Mean

- The soil moisture regimes of the new station may differ from the soil moisture regime of the *model development stations*.
- To cope with this, the *Deviation in Mean (DM)* computed by taking the difference between the mean of the surface SMC values of the *model development stations* (for the particular HSG) and the target station.
- The model estimated values are corrected for the deeper layers using the information of DM noticed in the surface layer to maintain the soil moisture regime for the target station.

SSMP Model Performance during Developing the Model

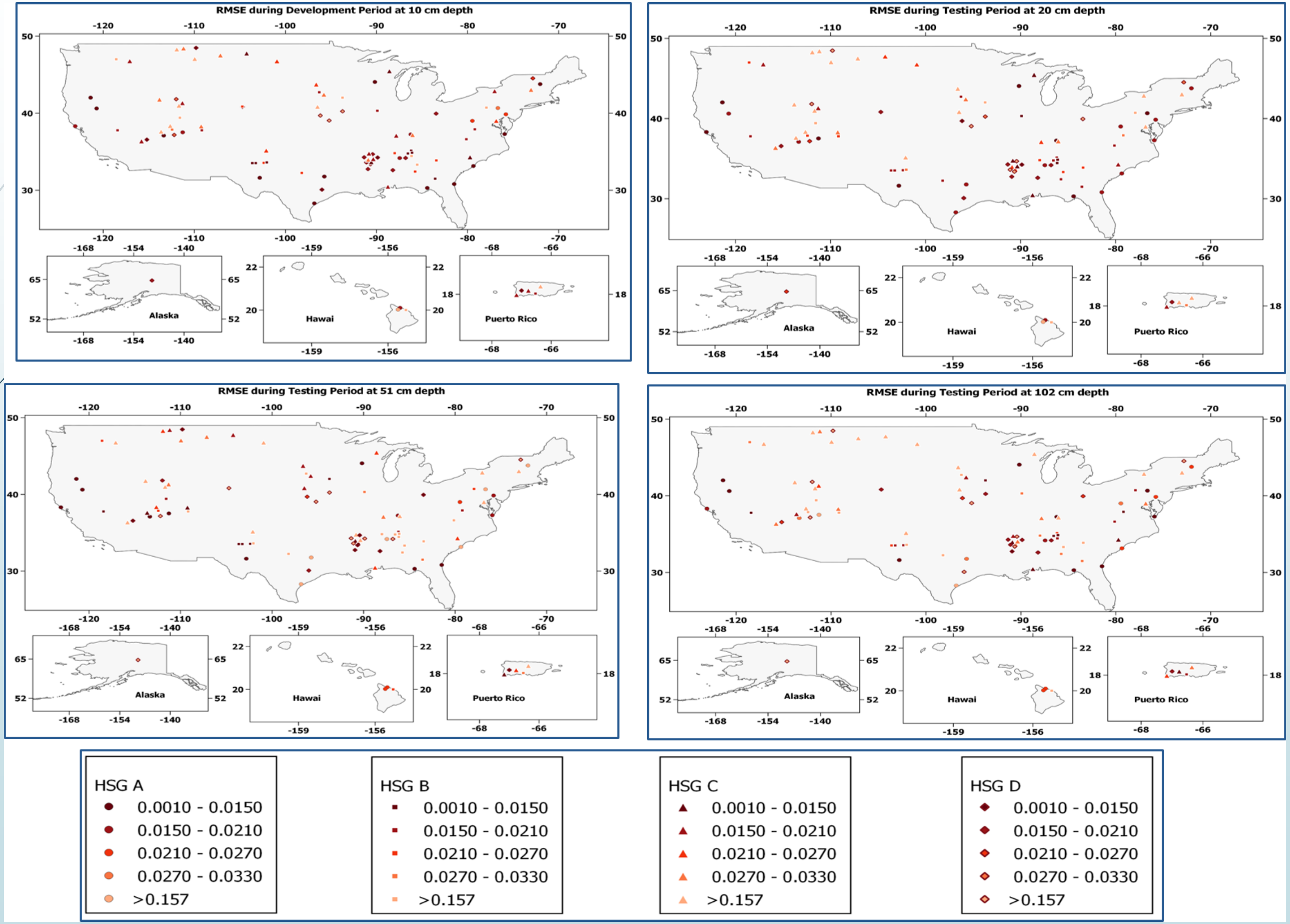


Comparison of mean values during (a) development period and (b) testing period. Comparison of standard deviation during (c) development period and (d) testing period for HSG A.

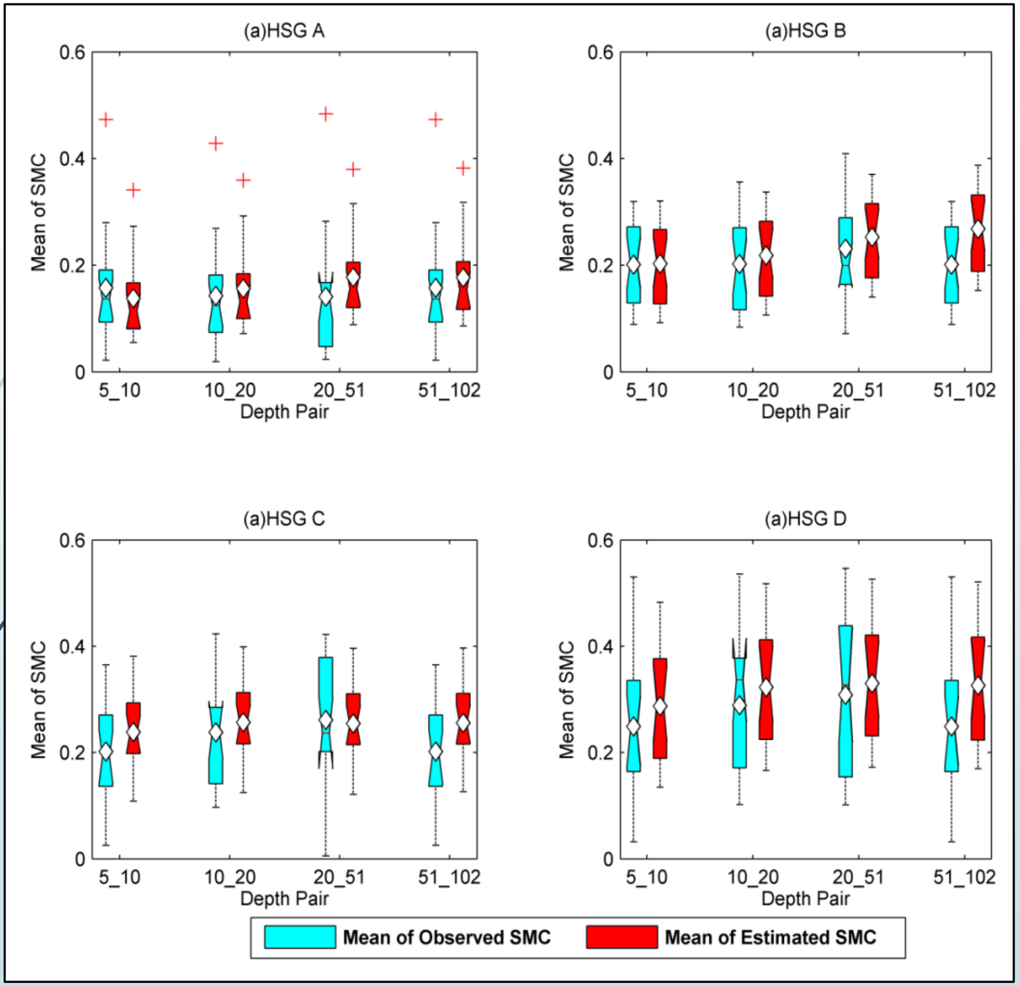


Comparison of observed and estimated SMC for all four depths of one station from HSG A

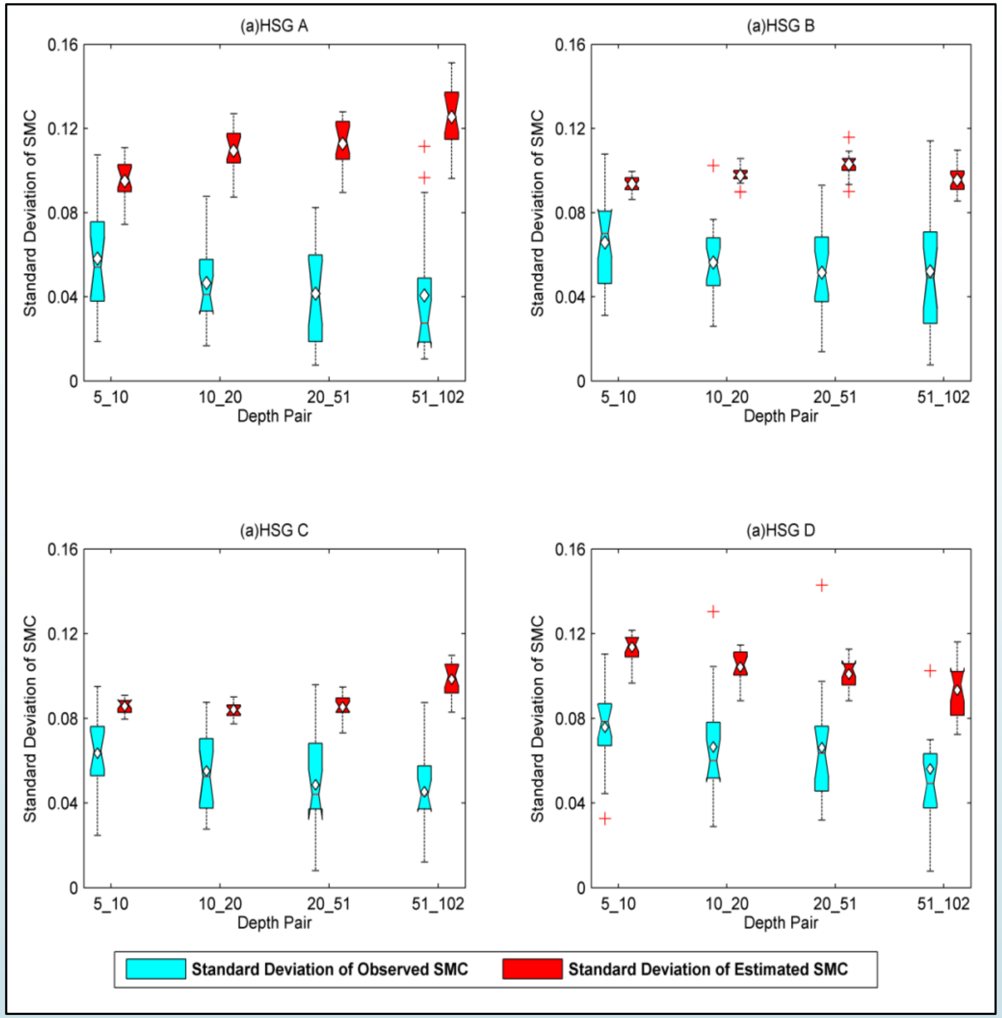
Spatial Variability of RMSE across the Model Developing Stations



SSMP Model Performance during Spatial Validation



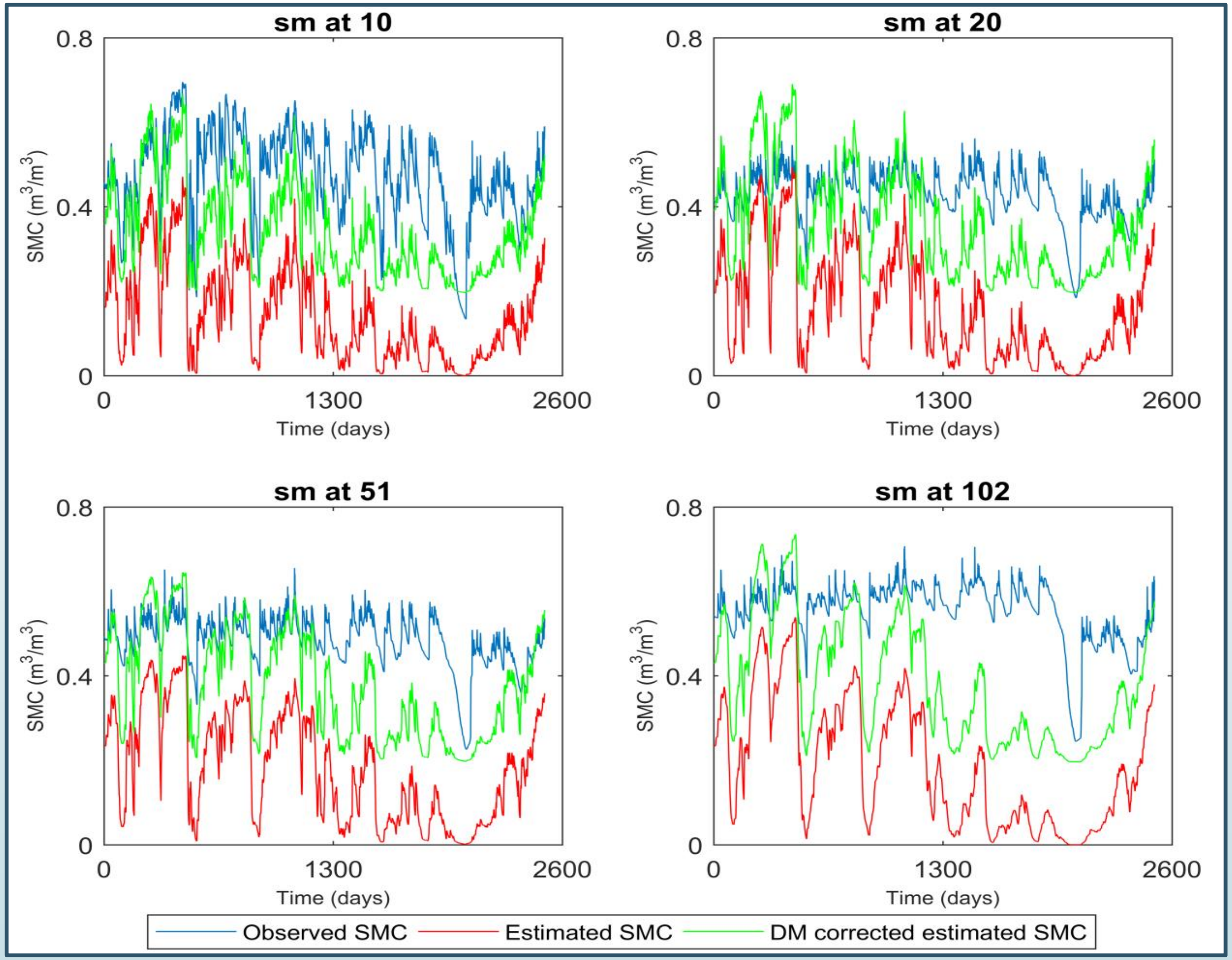
Comparison of mean values



Comparison of standard deviation values

a) Mean values of observed and estimated SMC data during development period; b) Mean values of observed and estimated SMC data during testing period; c) Standard deviations of observed and estimated SMC data during development period; d) Standard deviations of observed and estimated SMC data during testing period.

SSMP Model Performance during Spatial Validation



Time series plot of observed, estimated and DM-corrected estimated SMC of all four depths for one station selected for spatial validation from HSG A.

Take Home

- In this study, a spatially-varying Statistical Soil Moisture Profile (SSMP) model is developed.
- The key features of the SSMP model are – 1) estimating the vertical SMC profile using only the surface SMC; and 2) imparting the spatial transferability by incorporating the HSG information.
- During the model development the forcing components show the trend of decreasing in the direction of HSG A to HSG D i.e. the forcing coefficients are higher for high infiltration (HSG A) and low for low infiltration (HSG D) of the soil.
- This specific feature of the forcing components for different HSGs having different infiltration characteristics including the effects of soil hydraulic properties on SMC dynamics, justifies the applicability of the spatially varying SSMP model for each HSG group to new locations.
- For, both the cases (model development and spatial validation), the model performances indicate that the proposed spatially varying SSMP model is able to characterize the SMC at deeper layers from only the surface SMC information for all HSG.
- The model performance consistently decreases with increase in depths for all the four HSGs but still acceptable given the complexity of the model.

Concluding Remarks

➨ *Future Scope*

➨ Considering the key features of the developed model, future scope lies in the **integration of remotely sensed surface soil moisture content (0-5 cm) in the estimation of large scale fine resolution, vertical soil moisture profile (up to root zone).** It is expected to be useful information in several fields of applications.

Further Reading

Pal, M., and Maity, R. (2019), Development of a Spatially-Varying Statistical Soil Moisture Profile Model by Coupling Memory and Forcing using Hydrologic Soil Groups, Journal of Hydrology, Springer, 570 (2019), 141-155, https://doi.org/10.1016/j.jhydrol.2018.12.042.

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Development of a spatially-varying Statistical Soil Moisture Profile model by coupling memory and forcing using hydrologic soil groups

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ABSTRACT

Information on vertical Soil Moisture Content (SMC) profile is important for several hydro-meteorological processes. This study borrows the idea of coupling the memory and forcing from a previous study and develops a spatially-varying Statistical Soil Moisture Profile (SSMP) model to estimate the vertical SMC profile. It uses only surface soil moisture (0–5 cm) values and Hydrological Soil Groups (HSGs) information of the location. The focus of the study is incorporation of the HSG information to ensure the spatial transferability of the proposed model by capturing the spatial variations of soil moisture profile with the change in soil hydraulic properties. The wide range of soil moisture data for model development as well as for spatial validation is obtained from 171 stations from different networks of International Soil Moisture Network (ISMN) at five different depths, i.e., 5, 10, 20, 51 and 102 cm. The HSG information at the locations are extracted from the Web Soil Survey (WSS) database. The potential of spatial transferability of the SSMP model is assessed by applying it to the new stations within the corresponding HSG. Model performances are promising for all four depth pairs (5–10, 10–20, 20–51 and 51–102 cm) of all four HSGs during both model development and spatial validation given the model complexity. Hence, the spatially-varying SSMP model is suitable at the ungauged locations by incorporating the HSG information. The potential application of the proposed model shows the future scope to assimilate the satellite based surface SMC data into the model to develop a vertical soil moisture profile map over a large area.

1. Introduction

Soil Moisture Content (SMC) of the unsaturated zone i.e. the vertical soil moisture profile plays a significant role in determining the water and energy fluxes between soil and atmosphere (Famiglietti et al., 1998) as well as vegetation growth (Yang et al., 2012). Recently, the retrieval of surface SMC from remote sensing data is in the research interest due to its large scale and fine resolution estimation (Bertoldi et al., 2014). However, the remote sensing is capable of retrieving the soil moisture information only for the top few centimeters (5–10 cm) of surface layer (Kerr et al., 2010).

The surface SMC is associated with the root-zone SMC and it is possible to obtain soil moisture profile assessment using the surface soil moisture information (Calvet and Noilhan, 2000; Albergel et al., 2008; Singh, 2010) since it is coupled to root-zone SMC through diffusion processes (Singh, 2010). Utilizing this concept many studies have attempted to estimate the root zone soil moisture by extrapolating the surface soil moisture (Wagner et al., 1999; Manfreda et al., 2014; Manfreda et al., 2014; Renzullo et al., 2014; Dumedah et al., 2015). The data assimilation techniques and the exponential filter proposed by Wagner et al. (1999) are the most extensively used methods among these. The exponential filter needs the wilting level, field capacity, and porosity information and can be applied to the regions with same climatic and crop conditions. These pre-requisites limit the application of exponential filter as the information may not be available for the other ungauged locations. Its application is based on the assumption of a constant hydraulic conductivity of soil, whereas, in practical scenario it can vary by several degrees of magnitude. Soil moisture profile estimation from remote sensing data has focused on data assimilation into Land Surface Models (LSMs) based on the association of near-surface soil moisture and the root-zone soil moisture through diffusion processes. LSMs use the soil hydraulic property information derived from the pedotransfer function by Cosby et al. (1984) and a set of default or spatially uniform model parameters (Li et al., 2011). These simplified and empirically derived default soil hydraulic parameters are inadequate to describe the soil moisture variability in spatially heterogeneous landscapes. Thus, the uncertainties due to the inaccurate physical description of the water and energy balance hinder the application of such techniques (Sabater et al., 2007).

It is established that the mutual association of SMC values decreases

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Thank you