Validation and Calibration of HRLDAS Soil Moisture Products in Nebraska

Haoteng Zhao
Center for Spatial Information Science and Systems
George Mason University
Fairfax, VA, USA
hzhao22@gmu.edu

*Liping Di
Center for Spatial Information Science and Systems
George Mason University
Faitfax, VA, USA
ldi@gmu.edu

Ziheng Sun
Center for Spatial Information Science and Systems
George Mason University
Fairfax, VA, USA
zsun@gmu.edu

Eugene Yu
Center for Spatial Information Science and Systems
George Mason University
Fairfax, VA, USA
gyu@gmu.edu

Chen Zhang
Center for Spatial Information Science and Systems
George Mason University
Fairfax, VA, USA
czhang11@gmu.edu

Li Lin
Center for Spatial Information Science and Systems
George Mason University
Fairfax, VA, USA
llin2@gmu.edu

***Abstract*—Crop growth depends on the root-zone soil moisture (RZSM) (~top 1m). Accurate estimation of RZSM is vital to optimize irrigation management for saving water and energy while sustaining crop yield. The High-Resolution Land Assimilation System (HRLDAS) from NCAR can generate RZSM at field scales for irrigation management. The soil moisture data from various agriculture sites in the AmeriFlux network, U.S. Climate Reference Network (USCRN), and Soil Climate Analysis Network (SCAN) are used to verify the soil moisture products generated by HRLDAS. Although the HRLDAS products is not location specific and could be applied nationwide, this study will focus on Nebraska for evaluation, validation, and further calibration. We also compared NASA's SMAP surface soil moisture products to HRLDAS surface layer soil moisture. Since the accuracy of the SMAP product is known, this comparison directly validates the HRLDAS surface soil moisture product and indirectly validate its RZSM products. Results from these two validation methods show a good accuracy of HRLDAS soil moisture products. The conspicuous differences between HRLDAS and SMAP products indicate that HRLDAS omits the irrigation activities as its simulation is based on weather variables and energy balance. It's hard for HRLDAS to consider and include the irrigation actions in its results, while as SMAP products remotely sense the soil moisture as it is, the changes caused by irrigation are clearly reflected. Therefore, a simple calibration is applied to the HRLDAS products by including irrigation amount as its variables.**

Keywords—soil moisture, irrigation management, validation, HRLDAS, SMAP

I. Introduction

Crop growth depends on the root-zone soil moisture (RZSM) (~top 1 m). Accurate estimation of RZSM is vital to optimize irrigation management for saving water and energy while sustaining crop yield. Although the important role of soil moisture in the crop growth and irrigation management has been recognized [1], it remains the most difficult variable to obtain because there is no routine high-resolution observation of soil moisture at the continental scale. The High-Resolution Land Assimilation System (HRLDAS) [2] has been developed to fill this gap by simulating the evolution of land surface states, which, of course, includes the RZSM at field scale. It's necessary and important to validate the model simulated RZSM and other crop related data before we can apply them in irrigation management and other agricultural applications[3-5]. The accuracy of HRLDAS-derived soil moisture products has been verified against observations from the Oklahoma Mesonet[6, 7] in the past, which demonstrated that HRLDAS was able to capture the observed seasonal tendency of soil moisture evolution [2].

In the present study, the high-resolution regional soil moisture products that have been developed at 500-m spatial grid spacing in one hour intervals over Nebraska, U.S. are verified against both site-based ground measurements from various monitoring networks and gridded remote sensing soil moisture products from NASA's Soil Moisture Active Passive (SMAP) project [8].

II. Data And Method

The HRLDAS based on the Noah LSM is used to develop high-resolution soil moisture products. The HRLDAS obtained the surface forcing from the National Water Model standard analysis configuration[9], in which meteorological forcing data are drawn from the Multi-Radar/Multi-Sensor System (MRMS) Gauge-adjusted and Radar-only observed precipitation products along with short-range Rapid Refresh (RAP) and High Resolution Rapid Refresh (HRRR), while stream-gauge observations are assimilated from the United States Geological Survey (USGS). The initial values are derived from the North American Land Data Assimilation System (NLDAS) analysis. The HRLDAS is run for 3 years from 2019 to 2021 at 500 m spatial resolution for Nebraska region, and the output is saved in hourly intervals. The HRLDAS was configured for NLDAS to have 4 soil moisture layers with thicknesses (from top) of 10 cm, 30 cm, 60 cm, and 100 cm, for a total soil column depth of 2 meters.

Soil moisture from HRLDAS are validated against the ground truth observations and compared with existing satellite estimates. The soil moisture in situ observations are available at 11 stations from 3 different networks in Nebraska, among which 4 stations from Soil Climate Analysis Network (SCAN) [10], 4 stations from U.S. Climate Reference Network (USCRN) [11], and 3 stations from AmeriFlux network [12]. Figure 1 presents the distribution of these stations. The soil moisture data from different networks are measured at different depth, and due to the unavailability of continuous in situ observations, this study is confined to the growing season (April-October) only. Detailed depth information about the in-situ data is listed in Table 1. The satellite soil moisture products at 9 km resolution is derived from SMAP on a daily basis [13]. As

2022 10th International Conference on Agro-geoinformatics (Agro-Geoinformatics) | 978-1-6654-7078-0/22/$31.00 ©2022 IEEE | DOI: 10.1109/AGRO-GEOINFORMATICS55649.2022.9858974

978-1-6654-7078-0/22/$31.00 ©2022 IEEE

the SMAP rootzone soil moisture is not a direct observation, we only collected surface (top 5 cm) soil moisture maps for comparison with the top layer of HRLDAS soil moisture. Because the accuracy of SMAP products is known [14], this comparison directly validates the HRLDAS surface soil moisture and indirectly validates its RZSM product. SMAP soil moisture products are visualized on WaterSmart portal for Nebraska state [15], and on Crop-CASMA portal for U.S. continent [16]. An example of SMAP map is shown in Figure 2.

TABLE I. MEASUREMENTS DEPTHS OF DIFFERENT NETWORKS

Network	Depths
SCAN	5 cm, 10 cm, 20 cm, 50 cm, 100 cm
USCRN	5 cm, 10 cm, 20 cm, 50 cm, 100 cm
AmeriFlux	10 cm, 25 cm, 50 cm, 100 cm

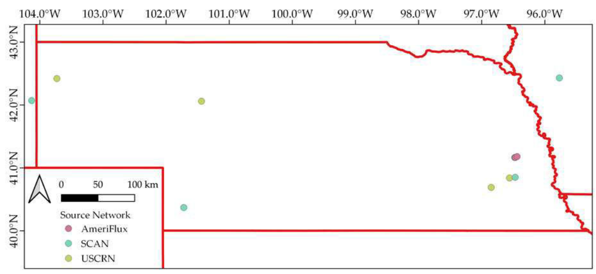

Fig. 1. Distribution of the in situ observations for soil moisture.

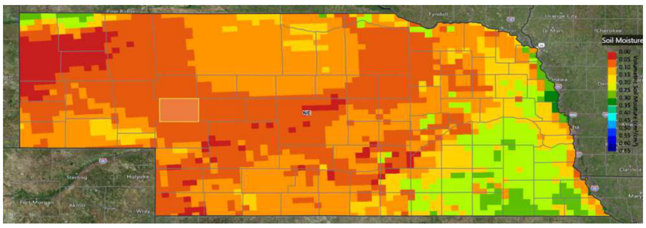

Fig. 2. Visualized example of SMAP surface daily map (06/09/2021) in Nebraska (from https://geobrain.csiss.gmu.edu/watersmartport/web/).

Because the in situ soil moisture were measured at different depth, they are converted to the HRLDAS soil moisture layers using a simple linear interpolation. The depth to the middle of the soil layers are 5 cm, 25 cm, 70 cm, and 150 cm. After removing the missing data, totally 83276 valid observations are collected. We used root mean square error (RMSE) as the metric to evaluate the accuracy.

III. RESULT AND DISCUSSION

We compare the spatial averaged soil moisture from all 11 stations with the respective average calculated from the model output (Figure 3). The observed volumetric soil moisture is generally high but decreases during the summer. This seasonality is closely related to the seasonal variation of evapotranspiration, which is mainly energy driven. Superimposed on this seasonal variation are shorter timescale variations that are driven by individual precipitation and irrigation events. Compared with the observations, the HRLDAS model has lower soil moisture values most of the time. The system bias is highest for depth 70 cm, about 10% (m^3/m^3). This bias is much lower at 5 cm and 25 cm depths. In year 2020, HRLDAS model soil moisture outputs are less accurate compared to other years. This might because 2020 is a dry year, more irrigation events were applied to crop fields. As HRLDAS is not able to simulate irrigation activities without further information, frequent irrigation would apparently affect its accuracy in simulation for crop fields. Nevertheless, the overall RMSE averaged over 11 stations are 0.06, 0.07, 0.14, and 0.07 for 5 cm, 25 cm, 70 cm, and 150 cm respectively, which are similar to former verification study of model simulated soil moisture [17], which demonstrates HRLDAS is able to capture the observed variation pretty well.

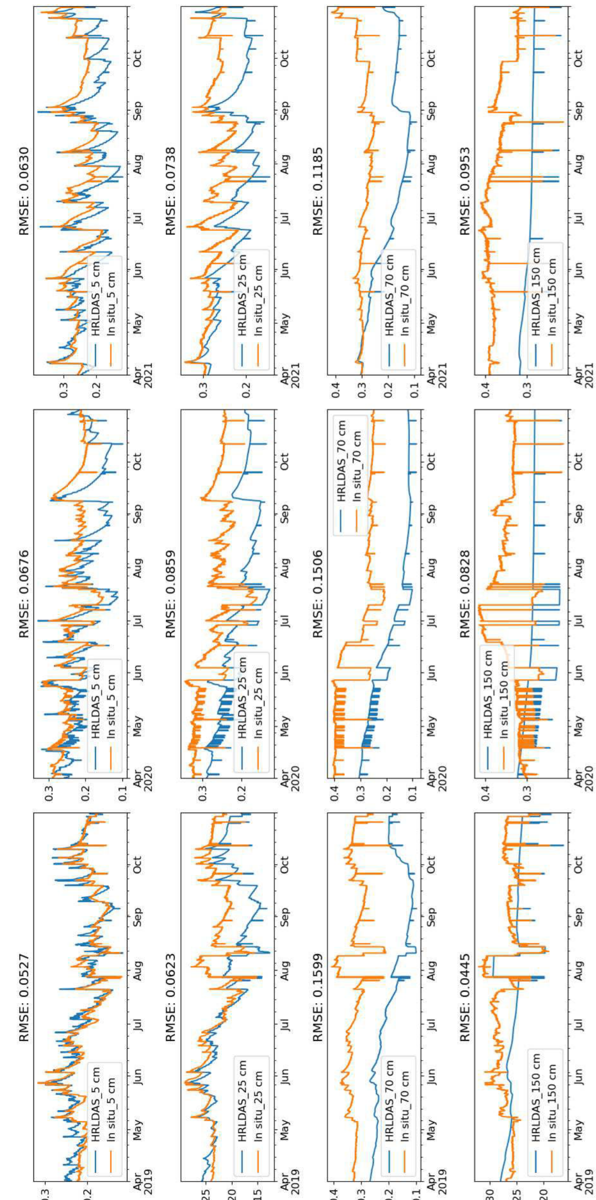

Fig. 3. Time series of the spatially averaged volumetric soil moisture for the growing seasons of 2019 to 2021. Depths: 5 cm, 25 cm, 70 cm, and 150 cm from top down. Blue is model soil moisture, and orange is in situ soil moisture.

The comparison with SMAP surface soil moisture outputs a map of RMSE (Figure 4). This map indicates that in 85.9% of the state area RMSE (m^3/m^3) of surface soil moisture is smaller than 0.10, and 56.7% of the state area has a RMSE less than 0.05. From the spatial pattern in Figure 4, we can roughly say that the high RMSE are mainly distributed in the urban area and irrigated fields.

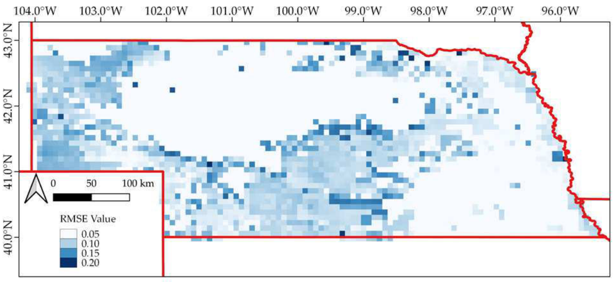

Fig. 4. RMSE map between SMAP daily surface soil moisture and HRLDAS top layer soil moisture from 2019 to 2021.

The analysis results of both in situ observations and satellite derived soil moisture have revealed that irrigation could affect soil moisture status greatly during growing season in crop field. Therefore, we proposed a simple calibration for HRLDAS soil moisture by incorporating irrigation during simulation. Irrigation schedule data are

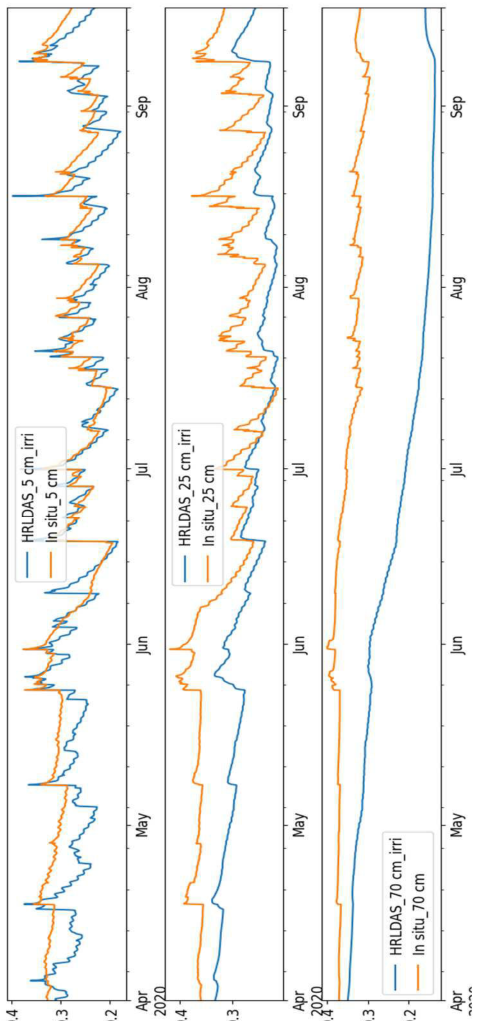

Fig. 5. Calibrated HRLDAS soil moisture and in situ soil moisture in 2020 growing season. Depth: 5 cm, 25 cm, 70 cm from top down. Blue calibrated HRLDAS soil moisture, and orange is in situ soil moisture.

collected for the 3 AmeriFlux sites in 2020 growing season. After digesting the irrigation amount in growing season, the calibrated soil moisture time series are shown in Figure 5. It's obvious that soil moisture at top 1 m is affected by irrigation events, presenting soil moisture peaks on irrigation dates. The comparison between in situ observations and calibrated HRLDAS soil moisture is shown in Figure 6, which indicates a decrease of RMSE (m^3/m^3) from 0.04, 0.07, 0.15 to 0.03, 0.05, 0.13 for 5 cm, 25 cm, and 70 cm layers respectively.

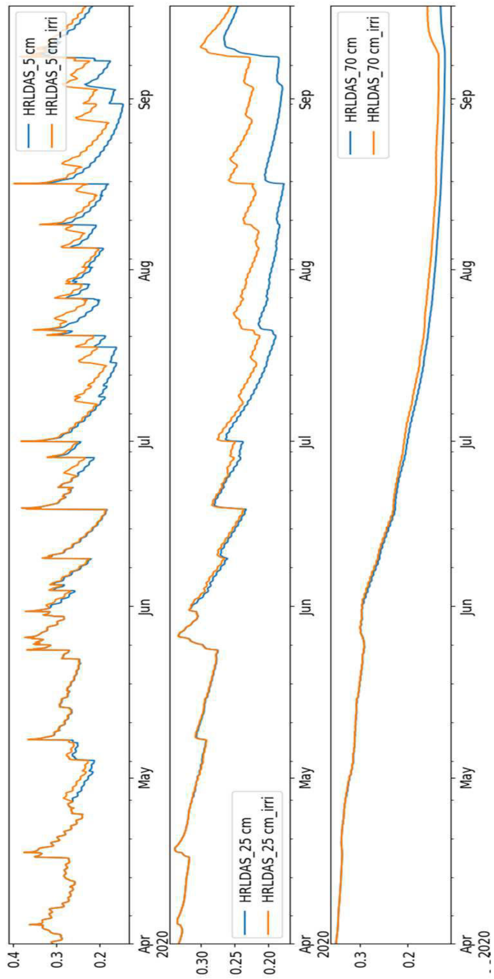

Fig. 6. HRLDAS soil moisture with and without irrigation information averaged over 3 AmeriFlux sites in 2020 growing season. Depth: 5 cm, 25 cm, 70 cm from top down. Blue is orignal soil moisture, and orange is calibrated soil moisture.

IV. Conclusion and Future Work

Soil moisture is one of the major factors for crop growth, and is essential for irrigation management. This paper aims to verify a model simulated soil moisture using in situ observations and remotely sensed soil moisture values to support irrigation management and other agricultural applications.

The soil moisture ground-truth data from various agriculture sites in the AmeriFlux network, USCRN, and SCAN were used to verify the soil moisture products generated by HRLDAS. We also compared NASA's SMAP surface soil moisture products to HRLDAS surface layer soil moisture. Results from these two validation methods show a good accuracy of HRLDAS soil moisture products.

The overall RMSE (m^3/m^3) are 0.06, 0.07, 0.14, and 0.07 for 5 cm, 25 cm, 70 cm, and 150 cm respectively, which is similar to former verification study of model simulated soil moisture.

Analysis of validation results also reveals that HRLDAS omits the irrigation activities as its simulation is based on weather variables and energy balance. It's hard for HRLDAS to consider and include the irrigation actions in its results, while SMAP products remotely sense the soil moisture as it is, thus the changes caused by irrigation are clearly reflected. Therefore, a simple calibration is applied to the HRLDAS products by including irrigation amount as its variables. The decreased RMSE between calibrated HRLDAS soil moisture and in situ measurements demonstrates that the HRLDAS soil moisture can be more accurate when on-site irrigation information is provided.

ACKNOWLEDGMENT

This research was supported by NSF WaterSmart project (CNS-1739705, PI: Liping Di).

REFERENCES

[1] H. Zhao et al., "Impacts of Soil Moisture on Crop Health: A Remote Sensing Perspective," in 2021 9th International Conference on Agro-Geoinformatics (Agro-Geoinformatics), 2021: IEEE, pp. 1-4.

[2] F. Chen et al., "Description and evaluation of the characteristics of the NCAR high-resolution land data assimilation system," Journal of applied Meteorology and Climatology, vol. 46, no. 6, pp. 694-713, 2007.

[3] L. Lin et al., "Validation and refinement of cropland data layer using a spatial-temporal decision tree algorithm," Scientific Data, vol. 9, no. 1, pp. 1-9, 2022.

[4] C. Zhang et al., "Rapid in-season mapping of corn and soybeans using machine-learned trusted pixels from Cropland Data Layer," International Journal of Applied Earth Observation and Geoinformation, vol. 102, p. 102374, 2021.

[5] L. Lin et al., "Improvement and validation of NASA/MODIS NRT global flood mapping," Remote Sensing, vol. 11, no. 2, p. 205, 2019.

[6] F. V. Brock et al., "The Oklahoma Mesonet: a technical overview," Journal of Atmospheric and Oceanic Technology, vol. 12, no. 1, pp. 5-19, 1995.

[7] R. A. McPherson et al., "Statewide monitoring of the mesoscale environment: A technical update on the Oklahoma Mesonet," Journal of Atmospheric and Oceanic Technology, vol. 24, no. 3, pp. 301-321, 2007.

[8] D. Entekhabi et al., "The soil moisture active passive (SMAP) mission," Proceedings of the IEEE, vol. 98, no. 5, pp. 704-716, 2010.

[9] B. Cosgrove et al., "An Overview of the National Weather Service National Water Model," December 01, 2016, 2016. [Online]. Available: https://ui.adsabs.harvard.edu/abs/2016AGUFM.H42B..05C.

[10] U. N. R. C. Service, "Soil Climate Analysis Network (SCAN)," U. N. R. C. Service, Ed., ed: NRCS, 2021.

[11] H. J. Diamond et al., "US Climate Reference Network after one decade of operations: Status and assessment," Bulletin of the American Meteorological Society, vol. 94, no. 4, pp. 485-498, 2013.

[12] D. Baldocchi et al., "FLUXNET: A new tool to study the temporal and spatial variability of ecosystem-scale carbon dioxide, water vapor, and energy flux densities," Bulletin of the American Meteorological Society, vol. 82, no. 11, pp. 2415-2434, 2001.

[13] R. Reichle, G. De Lannoy, R. D. Koster, W. T. Crow, J. S. Kimball, and Q. Liu., "SMAP L4 Global 3-hourly 9 km EASE-Grid Surface and Root Zone Soil Moisture Geophysical Data, Version 6. ," NASA National Snow and Ice Data Center Distributed Active Archive Center., vol. Boulder, Colorado USA. , 2021.

[14] P.-W. Liu et al., "Assessing Disaggregated SMAP Soil Moisture Products in the United States," IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 14, pp. 2577-2592, 2021.

[15] H. Zhao, L. Di, and Z. Sun, "WaterSmart-GIS: A Web Application of a Data Assimilation Model to Support Irrigation Research and Decision Making," ISPRS International Journal of Geo-Information, vol. 11, no. 5, p. 271, 2022.

[16] C. Zhang et al., "Crop-CASMA: A web geoprocessing and map service based architecture and implementation for serving soil moisture and crop vegetation condition data over U.S. Cropland," International Journal of Applied Earth Observation and Geoinformation, vol. 112, p. 102902, 2022/08/01/ 2022.

[17] A. Robock et al., "Evaluation of the North American Land Data Assimilation System over the southern Great Plains during the warm season," Journal of Geophysical Research: Atmospheres, vol. 108, no. D22, 2003.