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# APPLICATION OF TEMPERATURE AND VEGETATION INDEX FOR SOIL MOISTURE DOWNSCALING FOR AGRICULTURE

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## ABSTRACT

Information on the soil moisture content in the soil is important for planning both for farmers and agricultural water managers. The availability of this information is however limited owing to the expensive nature of in-situ soil moisture measurements and cloud conditions that limits satellite derivation of soil moisture and the availability of satellite derived soil moisture at coarse resolutions limiting their application at local scale. This study applies existing downscaling technique which makes use of vegetation indices and land surface temperature. The study compounds the technique with Harmonic Analysis of Time Series (HANTS) to provide continuous high-resolution soil moisture. The case study area is the state of Nebraska and the low-resolution soil moisture used is advanced Scatterometer (ASCAT). The use of HANTS successfully produced daily soil moisture estimates without degrading the accuracy of the soil moisture at 0.09m<sup>3</sup>/m<sup>3</sup>. The Precision however, was observed to be slightly degraded owing to seasonal variations and the different rooting depths within which the vegetation draws soil moisture from. Whereas the study has been conducted in Nebraska, the same can be replicated in regions with limited soil moisture measurements. The information is paramount for crop production forecasting, drought assessment and crop water management since it provides near real time information. This study shows that soil moisture downscaling can improve the resolution without degrading the accuracy. This accuracy was found to be within the threshold required for global climate observation systems (GCOS) which is set at 20% of the saturated water content.

## INTRODUCTION

Agriculture is key in achieving the UN sustainable development goals of ending hunger, increasing food production, doubling agricultural productivity and improving food security (Burney and Naylor, 2012; Pretty et al, 2011). Information on soil moisture content is paramount for crop management and thus the overall crop growth and development. Whereas this information is needed, its availability is limited due to the expensive nature of in-situ soil moisture measurements (Shin and Mohanty, 2013). Soil moisture from remote sensing is thus

offer a suitable alternative owing to its inexpensive nature. However, the soil moisture products are available at coarse resolutions. The challenge is further compounded by the presence of cloud cover which hinders retrieval of satellite data using the visible and near Infra-Red (NIR) Spectrum. This paper seeks to investigate the application of Harmonic Analysis of Time Series (HANTS) on the Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) (Roerink et al, 2010).

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This study considers using Temperature Vegetation Dryness Index (Petroopoulos, Carlson and Wooster, 2009) to downscale coarse resolution soil moisture. Satellite derived soil moisture from Advanced Scatterometer (ASCAT) available at a spatial resolution of 12.5 km resolution has been considered for this study owing to its independence of cloud conditions and high temporal resolution(daily) (Wagner et al, 2007). The land surface temperature and vegetation are used since they provide an indication of soil moisture status indirectly. Areas with high vegetation index depict low soil moisture stress while low vegetative index depict bare areas with limited moisture. However, it should be noted that there are areas that could be bare, for instance after land preparation but with high soil moisture. Land surface is thus used concurrently on the other hand depict the status of the surface irrespective of the vegetation status. The principle is that for a wet surface, due to evaporation, the surface tends to be cooler than the surrounding and the reverse is true for a dry surface. The use of LST with Vegetation Indices commonly referred to as LST/VI space has been widely used (Peng et al, 2015; Sandholt, Rasmussen and Andersen, 2002; Mallick et al., 2007).

The application of the VI/LST space has however been limited due to two reasons: cloud cover and time lag between successive satellite images. The study thus uses HANTS to provide continuous datasets and to remove outliers so as to provide daily TVDI estimates. The daily TVDI estimates are then applied on ASCAT to provide high resolution soil moisture for applications at local scale such as agricultural water management, crop water stress and yield estimation and for planning purposes.

## **METHODOLOGY AND DATA REQUIREMENTS**

The study approach entailed a three-stage process: First, the implementation of Harmonic Analysis of Time series on NDVI and LST to obtain continuous datasets. Secondly,

Temperature Vegetation Dryness Index is calculated using LST and NDVI space based on (Inge Sandholt, Rasmussen and Andersen, 2002). Lastly, the dryness index was used to downscale soil moisture retrieved from ASCAT from resolutions of 12km to low resolutions of 1km. The study has employed Three (3) statistical metrics which include mean bias error (MBE), root mean square error (RMSE), and Pearson's correlation coefficient (R) for assessment of the applied methodology. Figure 1 shows a summary of methodology. Figure 2(a) presents the soil moisture index obtained through inversion of temperature vegetation dryness index (TVDI) to a wetness index by subtracting it from 11 (1-TVDI). Figure 1 (c) is the volumetric soil moisture at coarse resolution obtained from ASCAT at 12.5 km resolution and while figures 2 (c) and (d) represents application of TVDI on the coarse resolution to obtain high resolution soil moisture at 1km.

### **2.2.1 Data Requirements**

**ASCAT Soil Water Index (SWI):** The satellite derived soil moisture was derived from ASCAT at 12.5km resolution. The soil moisture products come in eight index values (001,005,010,020,040,060,100). The indices refer to exponential filter applied to transform top layers to deeper soil moisture (Albergel et al., 2008) The study considers ASCAT-010 which is one of the products at top soil moisture level. The values indicate how strongly the soil moisture past soil moisture retrievals influences current conditions (Paulik, 2015). Thus, larger values tend to imply deeper soil moisture levels. The data was downloaded from Copernicus land Global Services (Copernicus Global Land Service, 2016).

**Land Surface Temperature (LST):** The 1 km LST composites were obtained from MODIS (MOD11A1) with a temporal resolution of 8 days (Z. Wan, S. H., 2015).

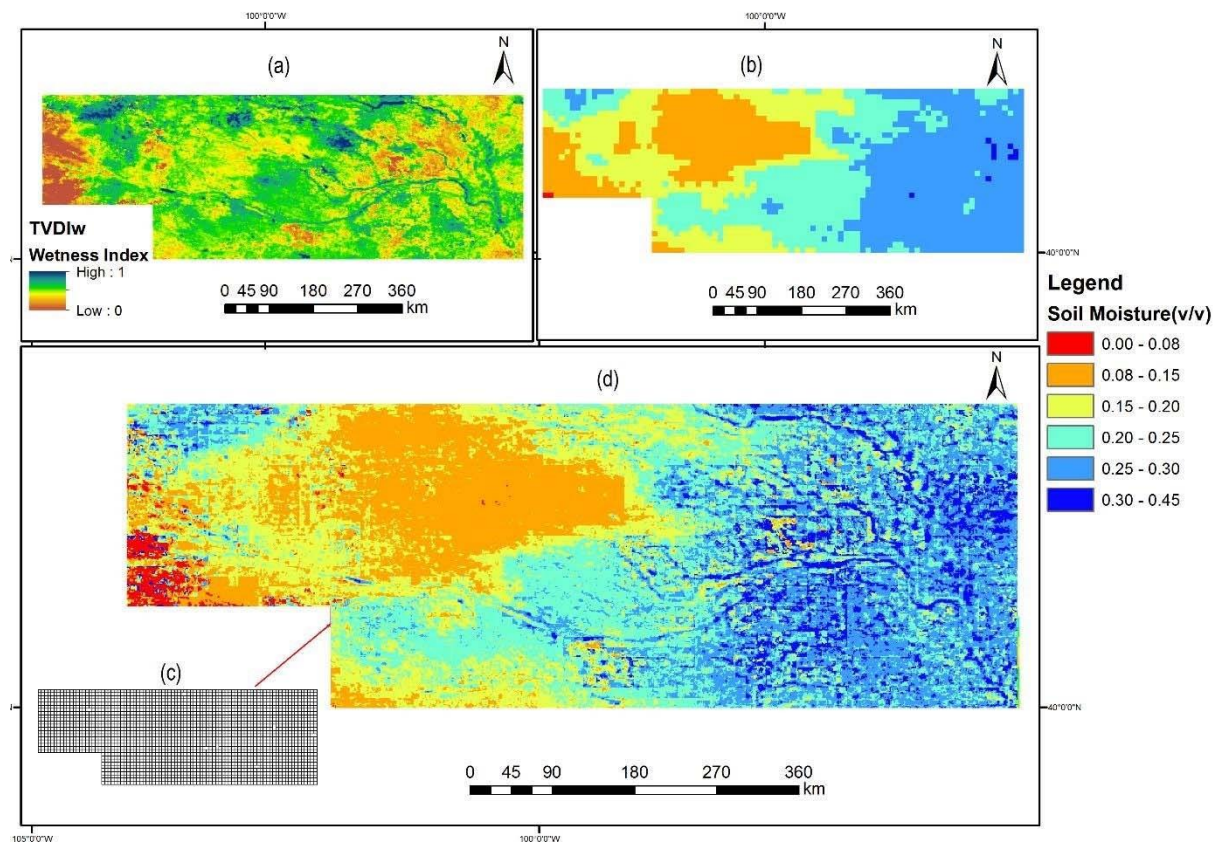
**Normalized Difference Vegetation Index (NDVI):** The NDVI data was retrieved from MODIS (MOD13Q1). The product is available at

250m resolution of 16 days (USGS LP DAAC, 2016).

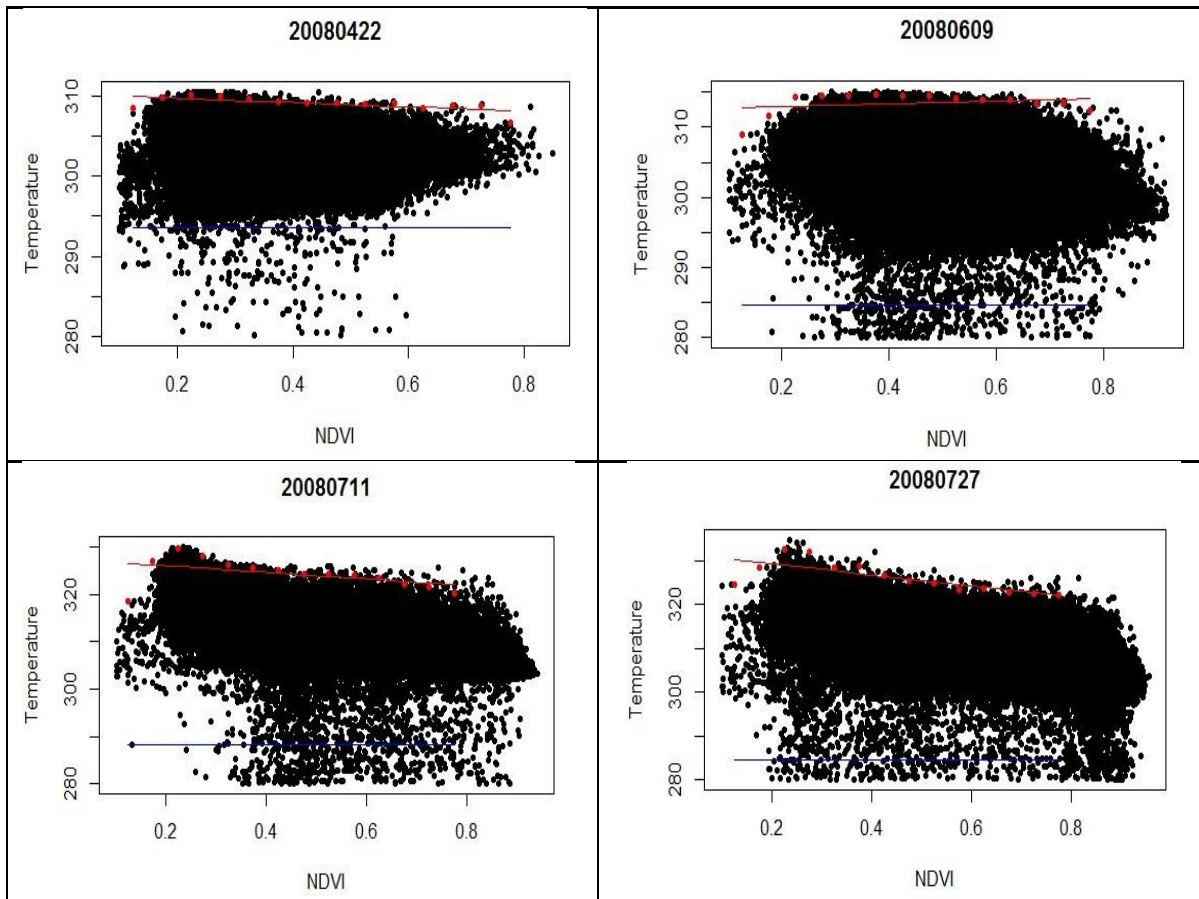
**Ground data:** The satellite derived soil moisture required validation with ground data to obtain the applied methodology performance. The ground data comprising in-situ volumetric soil moisture measurements were obtained from North-American Soil Moisture (TAMU) database available at Texas A&M University website (Texas A&M Geoservices, 2013). The datasets consist of 45 stations operated by different soil moisture networks across the State of Nebraska.

The challenge with using LST/VI space for estimating soil moisture is that it requires cloud free conditions. Figure 1 shows LST/VI space that was generated for ten (10) selected near cloud-free days for the year 2008. Whereas the ideal conditions were to have completely cloud free days for both LST and VI, only about three days out of the possible 365 days had LST/VI spaces that met this criterion (20080422, 20080812 and 20081031). It can be noted that there were still notable number of outliers indicating cloud interference for other images as indicated in the figure 2. The wet and dry edges outlined by blue and red lines respectively were used to calculate the dryness indices.

## RESULTS AND ANALYSIS



**Figure 1:** Implementation the downscaling Method for 10 May 2008;(a) Wetness indices obtained from temperature Vegetation Dryness Index (TVDIw) ranging between 0 for dry conditions and 1 for wet soils; (b) Volumetric soil moisture at coarse resolution (ASCAT 12.5km);(c) polygons representing each coarse resolution pixel; (d) downscaled soil moisture at 1km resolution using inverted TVDI for downscaling.



**Figure 2:** LST/VI scatter plots for selected cloud free days

Temperature vegetation dryness index was computed for both cloud free conditions and from images generated from HANTS implementation. From figure 3 it can be observed that similar patterns were obtained implying that the accuracy was not degraded through HANTS implementation. The main improvement being that daily TVDI could be obtained with on a daily scale with HANTS.

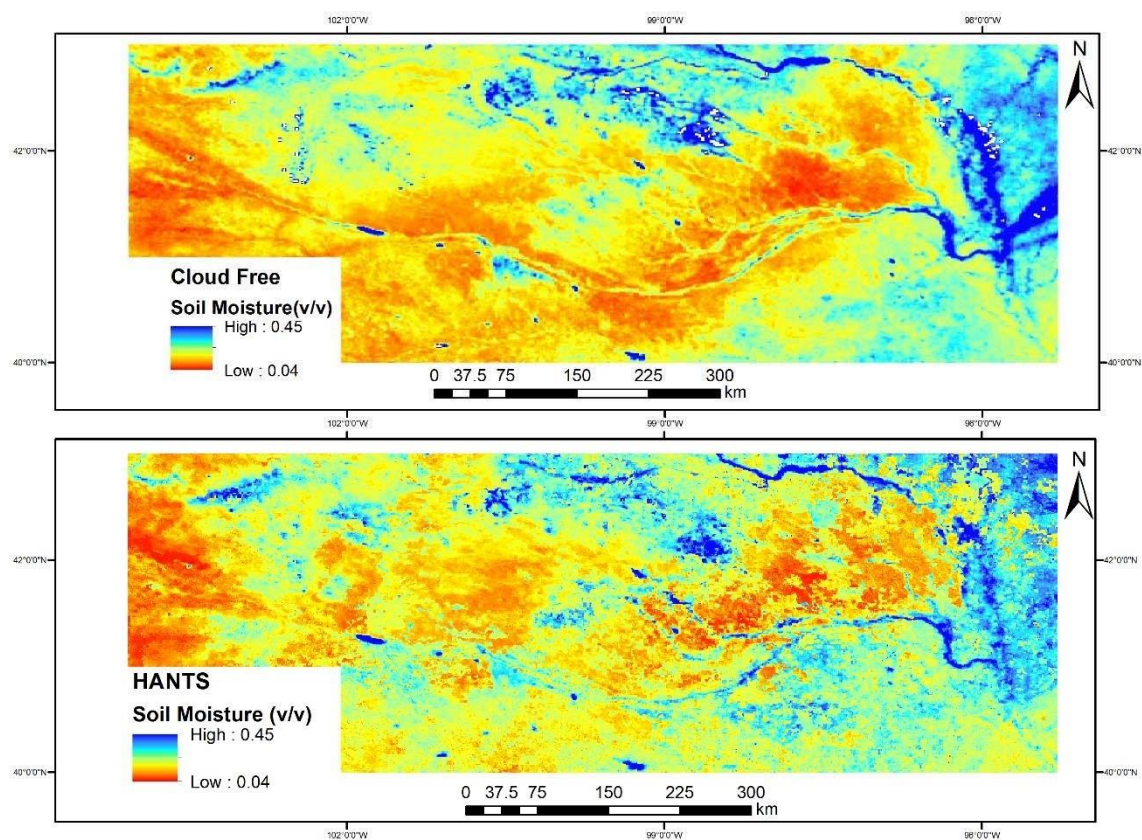
Figures 4 presents sample soil moisture graphs from selected soil moisture stations for the implemented downscaling methodology. The downscaled soil moisture is compared against in-situ soil moisture at 10cm and 25 cm depths below the surface. The implemented downscaling method makes use of the temperature vegetation dryness index (TVDI) based methods (Sandholt, 2002 and Hemakumara 2007).

The estimates from only 3 days that is; 20080422 (day 113), 20080812 (day 225) and 20081031 (day 305) with cloud free conditions has also been included for comparison.

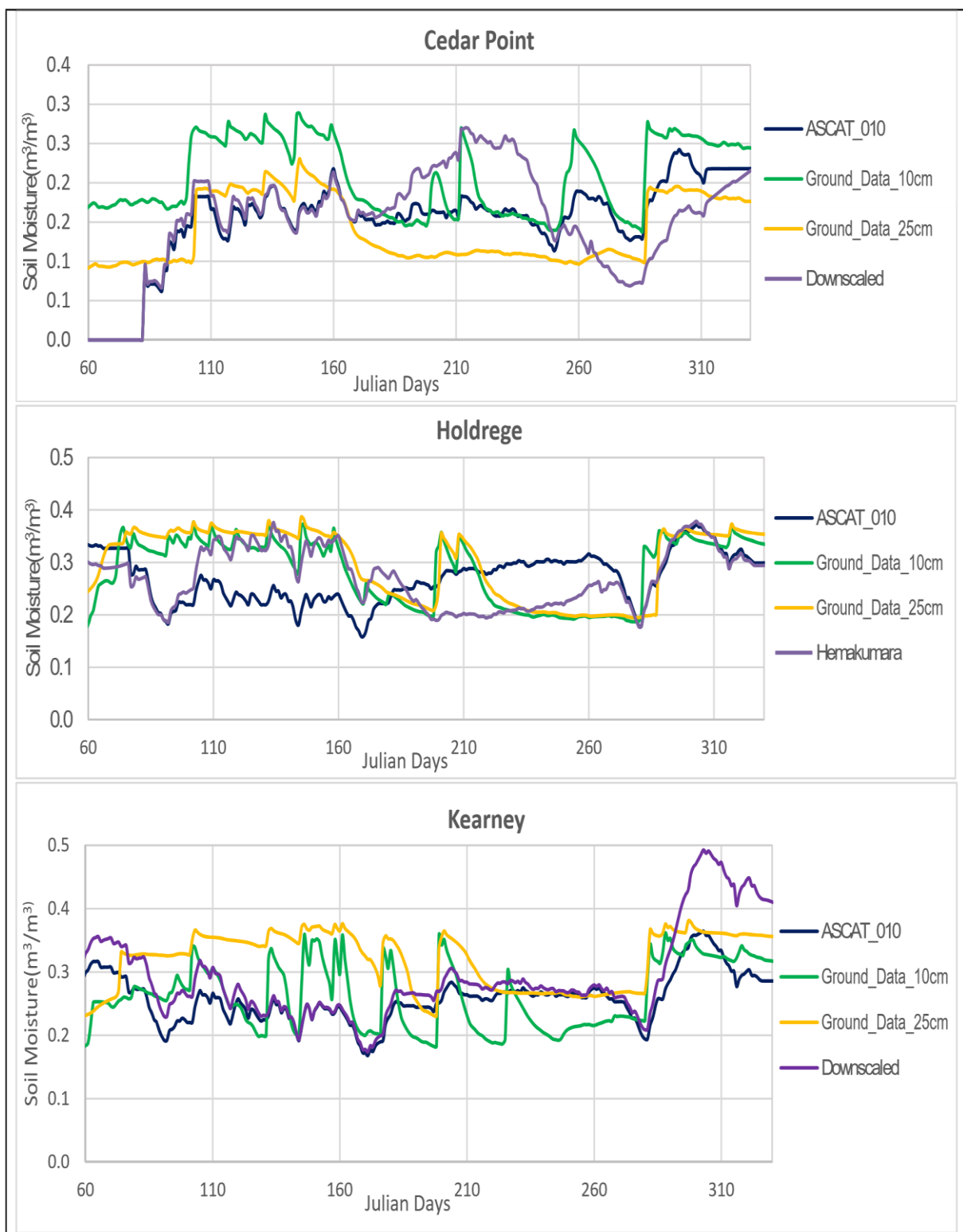
The downscaled soil moisture considers day 60 to day 330 of the year. This is because the months of December, January and February fall within winter and thus impractical to monitor soil moisture for agriculture as the ground is mostly covered with ice and hence no cropping activity.

The table 1 below presents the downscaling method performance relative to in-situ soil moisture measurements. The method showed minimal to no bias. The accuracy of the downscaled method was averaged at  $0.09\text{m}^3/\text{m}^3$ . The precision was shown to be between 0.33 to 0.35.





**Figure 3:** Soil moisture estimated from temperature vegetation dryness index for 22 August 2008. (a) Volumetric soil moisture estimates for cloud free conditions; (b) volumetric soil moisture estimates from HANTS implemented images (LST and NDVI)



**Figure 4:** Soil moisture graphs for selected soil moisture stations (Cedar Point, Holdrege, Kearney) for Julian Day 60 to Julian Day 330

**Table 1:** Performance of reviewed downscaling technique

Season	Depth	Retrieval Method	BIAS	MBE	RMSE	R
Annual	10cm	ASCAT_010	-0.02	0.08	0.09	0.47
		Downscaled	-0.02	0.09	0.10	0.33
	25	ASCAT_010	-0.01	0.08	0.10	0.48
		Downscaled	-0.01	0.09	0.10	0.34
Summer	10	ASCAT_010	-0.01	0.08	0.09	0.45
		Downscaled	-0.02	0.08	0.09	0.33
	25	ASCAT_010	0.00	0.08	0.09	0.49
		Downscaled	0.00	0.09	0.09	0.35

## DISCUSSION

The figure 4 above shows that the downscaled soil moisture was able to successfully capture the peaks which represent rain or irrigations events and the lows which represent low soil moisture levels. The use of HANTS was thus successfully able to produce daily soil moisture estimates without degrading the accuracy of the soil moisture estimates ( $0.09\text{m}^3/\text{m}^3$ ). The Precision however, was observed to be slightly degraded from 0.49 to 0.35. The low precision levels can be attributed to seasonal variations and the different rooting depths within which the vegetation draws soil moisture from. The latter for instance would require land cover to be considered as one of the parameters for downscaling. Additionally, soil type plays a major role as different soil types have differing saturation water content. Whereas the clay soil may be fully saturated, the total soil moisture held that is available for the plant will be limited. The improved performance during summer implies that the methodology can be applied for tropical regions and thus would be

appropriate for sub-Saharan Africa. Global soil moisture dataset was used for validation. Therefore, downscaling technique's performance can be further improved with the availability of higher resolution soil moisture information.

## CONCLUSION

The high-resolution soil maps were successfully generated from the original coarse resolution of 12.5km to 1km resolution. The downscaling method achieved an accuracy of  $0.09\text{m}^3/\text{m}^3$ , which is within the target accuracy estimated at  $0.10\text{m}^3/\text{m}^3$ . The global climate observation systems have put forward requirements for soil moisture derivation from satellites. The requirements are based on saturated soil moisture content with threshold of 20% of target accuracy. The downscaling thus successfully produced soil moisture estimates at high resolution for applications at local scale without degrading the overall accuracy of the satellite derived soil moisture at coarse scale. The overall

merit being that implementation of HANTS allowed daily soil moisture retrievals improving the temporal resolution of available high-resolution soil moisture. However, the accuracy and precision can be further improved by tacking cognizance of land cover heterogeneity, improved local soil data and bias correction attributed to seasonal variations. Whereas the study has been conducted in Nebraska, the same can be replicated in regions with limited soil moisture measurements. The information is paramount for crop production forecasting, drought assessment and crop water management, surface run-off determination and flood forecasting since it provides near real time information.

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