National Aeronautics and Space Administration

Retrieval of Field-Scale Surface Soil Moisture Over Corn, Soybean and Cotton Crops in the US South using Synthetic Aperture Radar (SAR) for the NISAR Mission

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1. Introduction

- Surface Soil Moisture (SSM) is an important parameter for the agricultural community due to its crucial role in drought assessment, precision farming, and irrigation scheduling etc.
- Field-scale (~ 200 m) SSM information at desired interval (~6 days) across the globe will be helpful to the farmers and government agencies for a better decision making and management.
- But, SSM products from the current missions are at tens of kilometers or downscaled to 3km. (Bauer-Marschallinger et al. 2019)

Motivation & Goal :

- NASA-ISRO Synthetic Aperture Radar (NISAR) mission
  - a dual-frequency L-&S-band SAR scheduled to launch in Jan 2024
  - Global high resolution (10 m) Single Look Complex (SLC) data
  - ~6 days revisit period (Ascending + Descending passes)
- To develop reliable algorithms for retrieval of 200 m SSM globally.
- Target accuracy of 0.06 m^3/m^3 to support NISAR's goal for SSM retrieval.

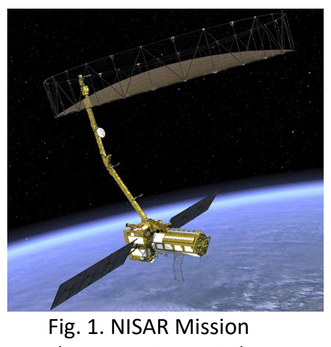


Fig. 1. NISAR Mission
(Source : JPL, NASA)

2. Physics-based Forward Scattering Models:

- SAR backscattering from vegetated soils is modeled using the scattering theory of Distorted Born Approximation (DBA) method which is sum of three dominant scattering as (Kim and Liao. 2021) :

$$\underbrace{\sigma^t_{pq}}_{Total} = \underbrace{\sigma^v_{pq}(VWC)}_{Volume} + \underbrace{\sigma^{sv}_{pq}(VWC,\epsilon,s,l)}_{Double-bounce} + \underbrace{\sigma^s_{pq}(\epsilon,s,l)exp\left(-2\tau_{pq}(VWC)\right)}_{surface} \quad (1)$$

- Pre-computed Look-Up-Table (LUT) representation of forward scattering models : ' Datacube '
- Datacubes for global IGBP landcover classes for NISAR incidence angles from 30° to 50° at 3° interval.

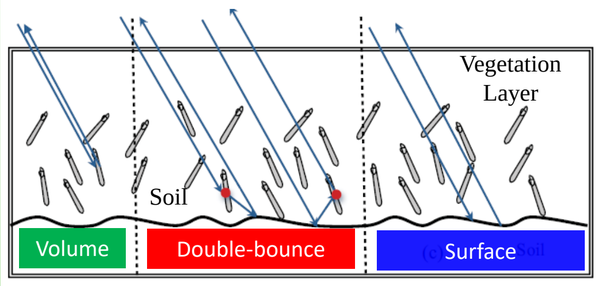


Fig. 2. Three scattering mechanisms modelled using DBA (a) Volume (b) Double-bounce (c) Surface. (Kim *et* al. 2014).

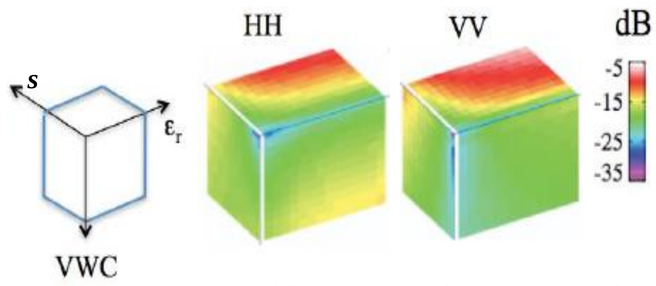


Fig. 3. An example of datacubes with three axes *S, ϵ_r* and VWC. (Kim *et* al. 2014).

3. Data Sets & Methodology:

- Retrieval algorithm is tested using airborne and spaceborne SAR over agricultural site in the US South.

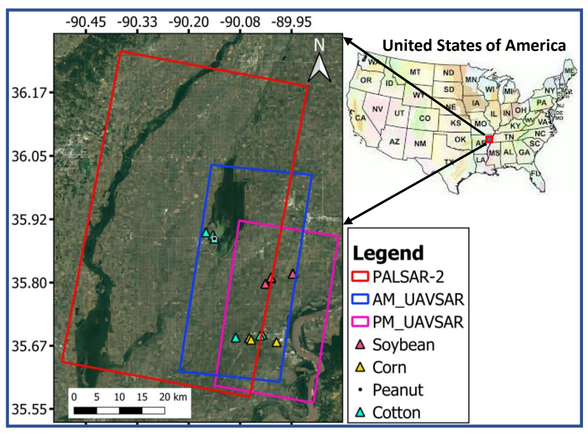


Fig. 4. Description of study area in Arkansas, US

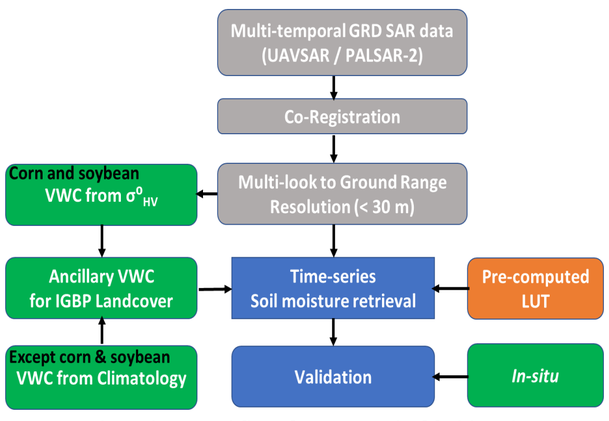
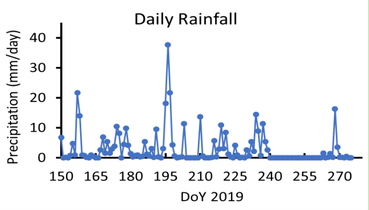


Fig. 5. Algorithm Workflow for retrieval of field scale SSM

- Cross-pol based Linear regression model from SMAPVEX12 campaign was used for VWC estimation.
- LUT has been inverted by minimizing measured and forward modelled backscattering coefficients (σ^0).

Table. 1. Details of airborne & spaceborne data and ground truth measurements

Sensor	Space Agency	Number of Scenes	Flight / Satellite Pass	Incidence Angle	SSM Range (m^3/m^3)	VWC Range (Kg/m^2)
UAVSAR	JPL, NASA	9 (7 + 2) (from June – September 2019)	Ascending (6AM) & Descending (6 PM)	25^0 - 65^0	0.05 – 0.6	0.0 – 4.0
PALSAR-2	JAXA	5 (from July – September 2019)	Ascending (6AM)	29^0 - 31^0	0.05 - 0.4	0.8 – 4.0



4. Validation of Multi-Angular UAVSAR Retrieval Results

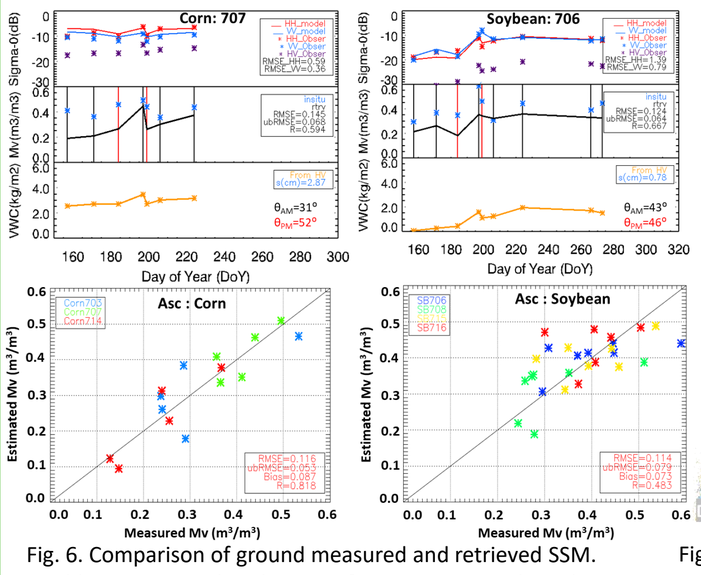


Fig. 6. Comparison of ground measured and retrieved SSM.

- Retrieved SSM captures the wet and dry down process. The retrievals are consistent across wide incidence angle range.
- Slight degradation in RMSE for combined Ascending and Descending flights.

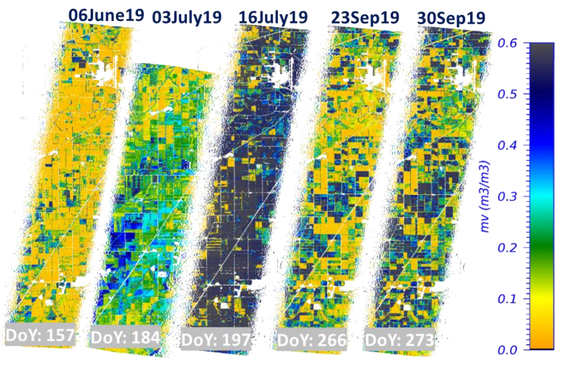


Fig. 7. Spatio-temporal variation of UAVSAR retrieved SSM

Table. 2. Statistical evaluation of UAVSAR retrieval results over 3 corn and 4 soybean fields from AM-PM campaign

Flight Pass	Corn (HH-VV) Results				Soybean (HH-VV) Results			
	RMSE (m^3/m^3)	ubRMSE (m^3/m^3)	Bias (m^3/m^3)	R	RMSE (m^3/m^3)	ubRMSE (m^3/m^3)	Bias (m^3/m^3)	R
Asc	0.116	0.053	0.087	0.818	0.114	0.079	0.073	0.483
Des	0.113	0.044	0.087	0.333	0.119	0.070	0.083	-
Asc + Des	0.111(0.11)*	0.080 (0.066)	0.065 (0.077)	0.623 (0.734)	0.119	0.079	0.082	0.476

* Except one point from one field.

5. Validation of ALOS PALSAR-2 Retrieval Results

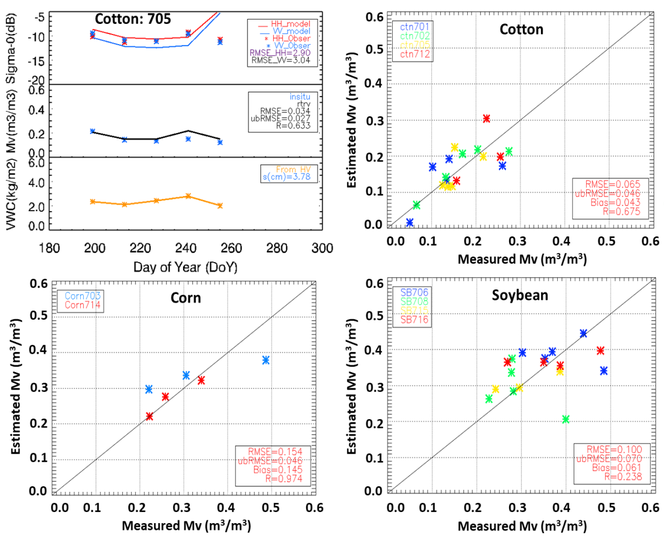


Fig. 8. Validation PALSAR-2 retrieval results.

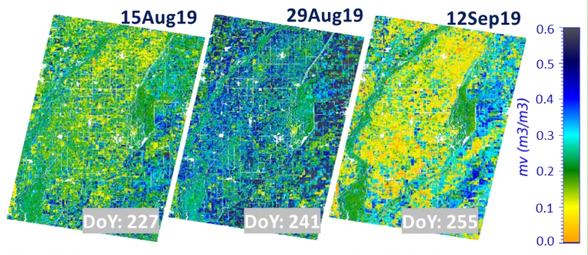


Fig. 9. Spatio-temporal variation of PALSAR-2 retrieved SSM

Table. 3. Retrieval performance using PALSAR-2 data

Crop	PALSAR-2 (HH-VV) Results			
	RMSE (m^3/m^3)	ubRMSE (m^3/m^3)	Bias (m^3/m^3)	R
Cotton (4 fields, 18 data points)	0.065	0.046	0.043	0.675
Corn (2 fields, 6 data points	0.154	0.046	0.145	0.974
Soybean (4 fields, 17 data points)	0.100 (0.079)	0.070 (0.042)	0.061 (0.064)	0.238 (0.773)

* Correlation except 1st day

- Successful results show that shrubland datacube can be used for cotton crops with VWC < 3 kg/m^2.
- The retrievals are within the target accuracy. Empirical relationship between σ^0_{HV} and VWC was found effective in correcting for the vegetation attenuation and scattering effects during SSM retrieval.
- Successes in SSM retrieval and VWC estimation are encouraging for future missions such as NISAR.

6. Summary

- The physics-based scattering models developed from SMAPVEX12 campaign have been inverted and validated over independent test site from NISAR AM-PM campaign. The successful results show the general applicability of the algorithm to map soil moisture across the globe.
- The current study has demonstrated the capability of physics-based scattering models to retrieve field-scale (~30 m) soil moisture over short (cotton and soybean) and tall (corn) crops using airborne UAVSAR and spaceborne PALSAR-2 data with unbiased RMSE of 0.044-0.080 m^3/m^3.
- The outcome of this study supports the NISAR's science goal to generate global field-scale (~200m) soil moisture products at 0.06 m^3/m^3 accuracy.
- VWC derived from σ^0_{HV} using SMAPVEX12 & AMPM'19 formula was effective in vegetation correction.
- Consistent retrieval using ascending (AM) and descending (PM) flights shows the capability of the algorithm to handle different incidence angle within the time-series.
- Investigation of retrieval results using single-polarization (HH or VV) input is under progress.

References

1. Bauer-Marschallinger et al. (2019). Toward global soil moisture monitoring with Sentinel-1: Harnessing assets and overcoming obstacles," *IEEE Trans. Geosci. Remote Sens*, vol. 57, no. 1, pp. 520–539.
2. Kim, S.B and Liao, T-H. (2021). Robust retrieval of soil moisture at field scale across wide-ranging SAR incidence angles for soybean, wheat, forage, oat and grass. *Remote Sensing of Environment*, 266, 1-14.
3. Kim, S.B., et al. (2014). Models of L-band radar backscattering coefficients over the global terrain for soil moisture retrieval. *IEEE Trans. Geosci. Remote Sens*. 52, 1381–1396.

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Publications:

1. Ponnurangam, G. G., Kim, S-B, Liao, T-H, Reba, M. and Cosh, M. (2022). Field-Scale Soil Moisture Estimation Under Corn and Soybean Crops Using Airborne SAR Data, *Proceeding of IEEE Geoscience and Remote Sensing Symposium (IGARSS'2022)*, pp. 5489-5492.
2. Ponnurangam, G. G., Kim, S-B, Reba, M. Zheng, Y., Liao, T-H, and Cosh, M.. Field-Scale Soil Moisture Over Corn and Soybean Croplands: Achieving Consistent Retrieval Between Ascending and Descending Flights from the AM-PM UAVSAR Campaign. *Remote Sensing*, in preparation.
3. Ponnurangam, G. G., Kim, S-B, and Reba, M . Surface Soil Moisture Retrieval and Validation Using PALSAR-2 Data Over Cotton Fields Through Inversion of Physical-Models. *IEEE GRSL*, in preparation.

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