# SOIL MOISTURE RETRIEVAL USING A TIME-SERIES RATIO ALGORITHM FOR THE NISAR MISSION

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## ABSTRACT

The NASA ISRO Synthetic Aperture Radar (NISAR) mission is currently under development and is scheduled for launch in 2022. The NISAR mission will provide global data sets of Earth land surface dynamics that are critical for multiple Earth Science disciplines including observations of ecosystem carbon and water cycles. Global L-band radar observations at high spatial resolution will be helpful for soil moisture applications. One of the goals of the NISAR mission is to provide a global soil moisture product at 200 m resolution with a global revisit frequency of 6 days. A time-series ratio algorithm was implemented using NISAR simulated SMAPVEX12 UAVSAR data, which is an L-band airborne radar backscatter measurement. For a NISAR-like configuration, backscatter at incidence angles from 30 to 50 degrees was considered in this study. The initial retrieval statistics following comparisons with in-situ ground truth show correlation coefficients (R) to be about 0.81, and the unbiased RMSE to be about 0.06 $m^3/m^3$. Results from dual co-polarization and/or cross-polarization modes were evaluated and considered for performance improvement.

***Index Terms—*** NISAR mission, Soil Moisture Retrieval, Time-Series Ratio Method, SAR, Remote Sensing

## 1. INTRODUCTION

NISAR (NASA ISRO Synthetic Aperture Radar) is a sweep SAR mission that utilizes L-band (1.26 GHz) backscatter measurements for various remote sensing applications that is scheduled be launched in winter 2022-2023 [1-3]. The mission can achieve a swath of greater than 240 km with a 12-day exact revisit sampling and 3-to-10-meter mode-dependent spatial resolution.

Estimating soil moisture is important for hydrological and agricultural applications. Previously, the SMAP (Soil Moisture Active/Passive) and SMOS (Soil Moisture/Ocean Salinity) missions have successfully performed soil moisture remote sensing. The NISAR mission will provide finer spatial resolution that may be of benefit for many applications.

The desire for finer spatial resolution in the retrieval of soil moisture has motivated numerous studies of the use of high-resolution synthetic aperture radar including those based on the use of backscatter powers, backscatter time series, repeat pass interferometric correlation or phase, and/or backscatter polarimetric decompositions, as well as other uses of SAR data to “downscale” other soil moisture products to finer spatial scales [4,5]. The unique capabilities of the NISAR mission clearly motivate its consideration for the production of field-scale soil moisture products, particularly given the fact that no other mission explicitly focused on soil moisture remote sensing is currently planned for launch during the NISAR operational period.

In general, the presence of vegetation greatly increases the complexity of electromagnetic backscattering, so retrieving soil moisture information from vegetated areas is challenging. However, previous studies [8,9] have shown that a time-series method can remain applicable for many vegetation types. A time-series ratio approach is therefore investigated in this paper for retrieving soil moisture from radar backscatter time series measurements [6-9].

For pre-launch algorithm implementation and validation, datasets from the SMAP Validation Experiment 2012 (SMAPVEX12, Winnipeg in Manitoba, Canada) field campaign acquired with NASA’s airborne L-band UAVSAR instrument were analyzed. The goal of the paper is to examine the retrieval performance achieved as a preparatory activity for soil moisture retrieval with NISAR.

## 2. TIME-SERIES RATIO ALGORITHM

L-band backscatter is a function of land surface conditions (e.g., soil moisture, vegetation), which vary both in space and time. NISAR's L-band frequency provides significant penetration into vegetated regions, allowing continued measurements of soil moisture even for mature crop regions. The 12-day exact repeat also allows the creation of interferometric products, so that in addition to instantaneous NRCS measurements, the amplitude and phase of correlations between passes can be examined (not considered in this paper).

The backscattered normalized radar cross section (NRCS) for a vegetated soil layer is a function of parameters related to soil, vegetation, and roughness, making the inverse problem of solving for soil moisture more difficult. A time-series ratio method assumes that the surface roughness and vegetation properties remain almost constant over two consecutive measurements. Thus, the ratio of consecutively measured NRCS values at time and can be approximated as

$$\frac{\sigma_{PP}^{0}(t_2)}{\sigma_{PP}^{0}(t_1)} \approx \left|\frac{\alpha_{PP}(t_2)}{\alpha_{PP}(t_1)}\right|^2 \quad (1)$$

where the alpha coefficient ($\alpha_{PP}$) is the first-order scattering amplitude of the small-perturbation model (SPM) with PP (Either HH or VV) polarization, so that the ratio is a function of the dielectric constants of the soil and the incidence angle.

With a time-series of N NRCS observations, N-1 ratio values are obtainable. The linear least-squares problem of the combined N-1 by N matrix equation is solved for the alpha coefficient at each time step by incorporating ancillary information on the maximum and minimum soil moisture over the time series. Finally, soil moisture is inverted from the alpha coefficients using the Mironov dielectric model [10].

## 3. PRELIMINARY RESULTS USING SMAPVEX12 UAVSAR DATA

The SMAPVEX12 field campaign was conducted in Winnipeg, Manitoba (Canada) from June 6 to July 17, 2012, in order to provide data to develop and evaluate soil moisture retrieval algorithms for the SMAP mission [11]. During the campaign, NASA's L-band UAVSAR (Uninhabited Aerial Vehicle Synthetic Aperture Radar) collected backscatter data a 7 m spatial resolution. In-situ soil moisture and vegetation biomass observations over fifty-five agricultural and four forest sites are also available.

The NISAR project re-processed the UAVSAR data for a NISAR-like configuration (HH 20MHz bandwidth and VV 5 MHz bandwidth) that was aggregated to 200m resolution for soil moisture retrievals. Multiple UAVSAR flight lines between June 17 to July 17, 2012 were used for this analysis (11 days on flight line 31604 and 14 days on flight line 31606).

Figure 1 shows the obtained soil moisture retrievals on June 23, 2012 for the 31604 and 31606 flight lines, respectively. For this example, soil moisture retrievals determined from VV-polarized backscatter data are shown on an EASE2. A subset of the in-situ sites (i.e., Sites 101-105) were excluded from this analysis as they were reported to have standing water during this period. Also, in the image, some areas are marked "blank" because they are not processed due to the inapplicable land types, such as rivers, roads, urban areas, and unclassified landcover classification. In Figure 1, the southern agricultural areas are somewhat dry and the upper forest areas are wet. Finally, a composite image was obtained by overlaying the two 31604 and 31606 flight line images. If two retrievals were available at a given pixel, the average value of two was represented.

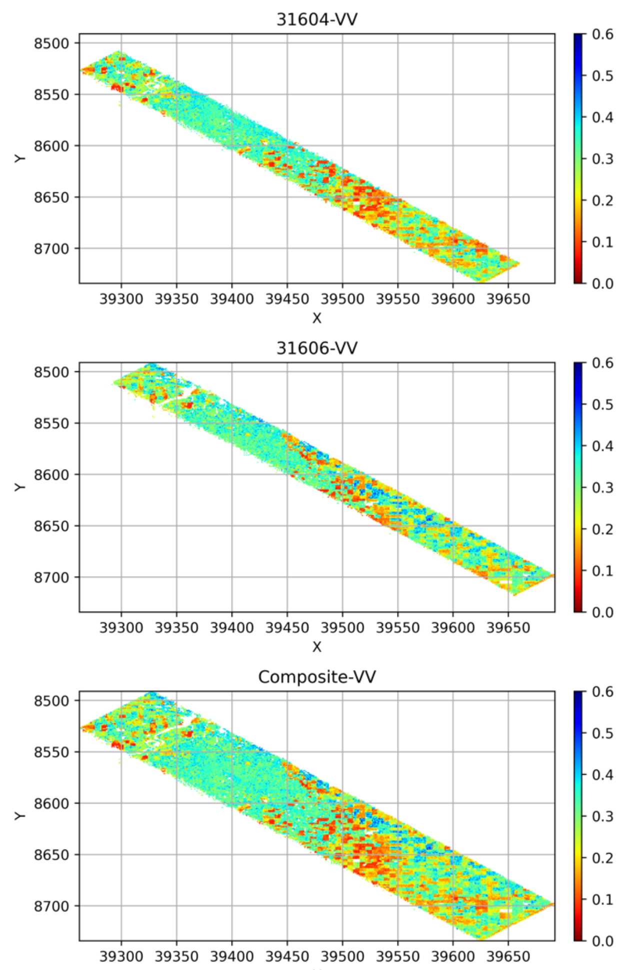


Fig 1. Soil Moisture Estimates (VV polarization) on June 23, 2012: (a) Flight Line 31604, (b) Flight Line 31606, (c) Composite Image of (a) and (b)

Data for 11 flight days was processed and compared with in situ observations. Figure 2 provides scatter plots comparing retrieved values to those measured at in-situ sites using all 11 days of data. For both flight lines, the correlation coefficients (R) are over 0.8 and the unbiased RMSE is around 0.06 $m^3/m^3$. The overall performance of flight line 31604 is slightly better than that of flight line 31606 due to the presence of high clay fractions and wetter soils in Northern portions of the domain. In the scatter plot, each crop type is marked with a separate color, and detailed statistics per crop type are provided in Table 1. Overall, the performance for oats, canola, and broadleaf types are better than average, while those for soybeans are worse than the average.

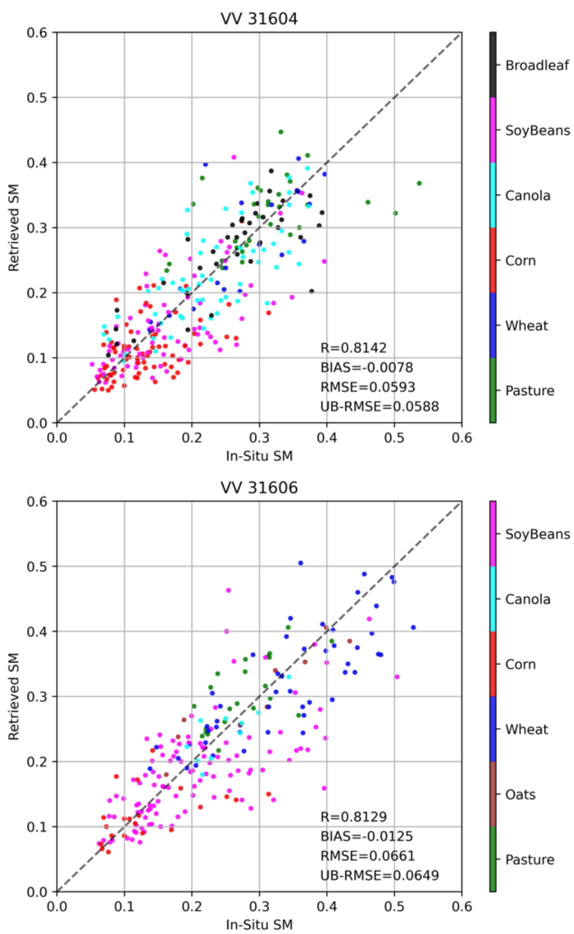


Fig 2. Scatter Plots between in-situ Soil Moistures and Soil Moisture Estimates (11 days, VV polarization): (a) Flight Line 31604, (b) Flight Line 31606.

| | Flight Line 31604 | | | |
|---|---|---|---|---|
| | Bias | RMSE | UB-RMSE | R |
| Pasture | 0.0080 | 0.0736 | 0.0732 | 0.4712 |
| Wheat | -0.0033 | 0.0559 | 0.0558 | 0.7705 |
| Corn | -0.0196 | 0.0549 | 0.0513 | 0.4941 |
| Canola | -0.0001 | 0.0553 | 0.0553 | 0.7549 |
| SoyBeans | -0.0160 | 0.0635 | 0.0615 | 0.6692 |
| Broadleaf | 0.0046 | 0.0528 | 0.0526 | 0.7981 |
| ALL | -0.0078 | 0.0593 | 0.0588 | 0.8142 |
| | Flight Line 31606 | | | |
| | Bias | RMSE | UB-RMSE | R |
| Pasture | 0.0279 | 0.0508 | 0.0425 | 0.6664 |
| Oats | 0.0079 | 0.0385 | 0.0377 | 0.9344 |
| Wheat | -0.0172 | 0.0628 | 0.0604 | 0.8069 |
| Corn | -0.0161 | 0.0646 | 0.0625 | 0.4568 |
| Canola | -0.0048 | 0.0270 | 0.0266 | 0.8148 |
| SoyBeans | -0.0205 | 0.0745 | 0.0717 | 0.6672 |
| ALL | -0.0125 | 0.0661 | 0.0649 | 0.8129 |

Table 1. Error Statistics of Time-Series Ratio Algorithm per crop type and flight line (11 days, VV polarization)

## 4. CONCLUSIONS

The results from this initial examination of soil moisture retrieval for NISAR using a time-series ratio algorithm are encouraging. On average, an unbiased RMSE of 0.06 $m^3/m^3$ was obtained, with the results varying moderately by flight line and crop type. The results suggest that this method will be able to meet the NISAR soil moisture accuracy goals of 0.06 $m^3/m^3$ unbiased RMSE. This method is advantageous in that it does not require any forward modeling of the backscattered NRCS. The method can be extended to use dual co-pol (both HH and VV) data, and the cross-pol data may be used to filter out inapplicable classes or for retrieving vegetation information. Updated results on the development of this approach for the NISAR soil moisture product will be presented at IGARSS 2021.

## 5. REFERENCES


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