Potential of the modified water cloud model to retrieve soil moisture within a drip irrigation context in pepper fields using ALOS-2 and Sentinel-1 data

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Abstract

In this paper, we examine the sensitivity of the modified water cloud model to soil moisture using co-polarized ALOS-2 L-band data in Horizontal-Horizontal (L-HH) polarization and C-band data (Sentinel-1) in Vertical-Vertical (C-VV) polarization over in pepper crop fields drip irrigated in the centre of Tunisia. By considering the context of spatially heterogeneous soil moisture, the total backscattering is the sum of pepper row scattering weighted by the vegetation cover fraction (Fc) and the inter-row soil scattering weighted by (1-Fc). The vegetation row contribution is the sum of pepper contribution and the underlying soil components attenuated by the vegetation cover. Various simulations are performed under different conditions of soil moisture and vegetation biophysical properties to assess the proposed model performance. The results highlight the potential of the proposed model to simulate SAR signal where cover fraction and pepper height values are under 0.4 and 0.5 m, respectively, using L-HH and cover fraction value under 0.3 and vegetation height value 0.3 m, using C-VV data in different contexts of soil moisture.

Keywords : soil moisture, drip irrigation, radar, Sentinel-1, ALOS-2, modified Water Cloud Model

Introduction

To ensure the food security, the agricultural water demand is increasing with the continuous demographic growth. Therefore, the irrigated spaces are extending especially in semi-arid and arid areas where the water resources are under the pressure of scarcity and quality deterioration [1]. This situation requires an optimized strategy to manage the available water to irrigate starting from a field scale to regional one [2]. Over decades, remote sensing products have proved their relevance as a tool to detect and map the irrigation zones and to manage the irrigation schedules by governing the spatiotemporal distribution and the amount of irrigation doses using the soil moisture information [3], [4]. As sensitive data to soil moisture, several works using the Synthetic Aperture Radar (SAR) data were devoted to irrigation management [5] . To our knowledge, few works investigate the soil moisture retrieval using SAR data at a field scale in inter-pixel heterogenous vegetation locally drip irrigated. To simulate radar signal over covered fields, several models can be used such as Karam as a physical model [6] and semi-empirical ones such as Michigan Microwave Canopy Scattering model [7]and the mostly used the Water Cloud Model (WCM) [8]. Owing to its simplicity, the WCM is the sum of three terms : vegetation scattering term, bare soil part attenuated by vegetation term ,and the soil–vegetation interaction terms. To simulate the SAR signal over bare soil part , WCM is generally associated with empirical equations [5], [9], Integral Electromagnetic Model (IEM), modified IEM [10] or Oh models [11]. The vegetation contribution in the WCM, is described by in-situ measurements such as Vegetation Water Content, Leaf Area Index, biomass, or derived information from optical data such as the Normalized Difference Vegetation Index. The interaction term is generally neglected due to its complexity to be considered and calculated. Hence, the majority of the developed studies used the X and C-bands' data due to the lack of L-band acquisitions availability. The launch of several satellites working in L-band frequency for example the Advanced Land Observing System-4, Tandem-L and the Radar Observation system for Europe in L-band.

In the present study, we investigate the potential of low frequency SAR data (C and L bands) to estimate the surface soil moisture in inter-pixel heterogenous spatial distribution context using a modified WCM over pepper fields located in a semi-arid area in the centre of Tunisia. This paper is divided into three parts. In the first part, we describe the study area and the used dataset. We detail the methodology in a second part. The third part is devoted to results and discussion followed by conclusions.

1. STUDY ZONE AND DATA BASE

1.1. Study area

The pepper reference fields are located in the Merguellil plain (Figure 1). It's a flat landscape in the center of Tunisia belonging to Kairouan governorate (9°230– 150 10°170E, 35°10–35°550N).The study area is characterized by a semi-arid to arid climate with annual average of precipitation around 300 mm/year [12]. The pepper cultivation is dominant in Kairouan as a summer crop garden, locally irrigated by drips. It's a row crop separated by 1 m of bare soil. In this context, we have heterogeneous vegetation repartition subsequently inter-pixel heterogenous soil moisture context.

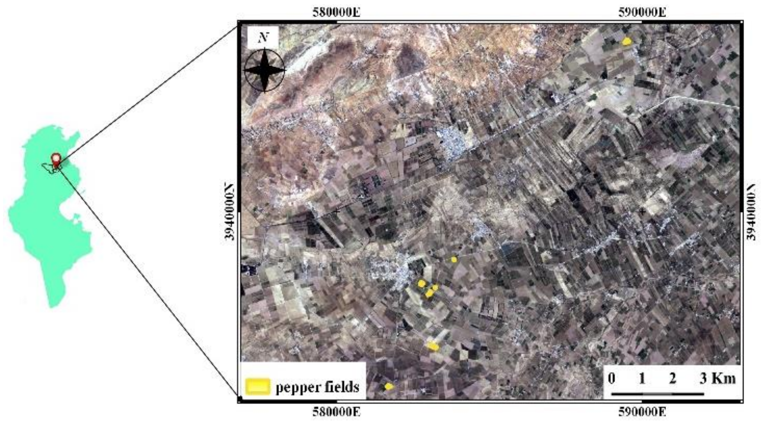

Figure 1. Pepper reference fields' location in the Merguellil plain (Center of Tunisia).

1.2. Data Base

1.2.1. In-situ measurements

During SAR data acquisitions, ground data collect companies were conducted over seven pepper fields during June, July and august 2020. The in-situ measurements included Leaf Area Index, vegetation cover fraction, and vegetation height measurements for peppers and roughness and soil moisture measurements for soil. In heterogenous context and based on the ground observations, we calculate an average soil moisture per field as the sum of 15% of the soil moisture of vegetation row directly irrigated by drips $\mathbf{Mv_{veg-row}}$ and 85% of the bare soil moisture $\mathbf{Mv_{inter-row}}$.

1.2.2. Satellite images

Tanks to the Sentinel1-A and B launch, C-band products are available in different types with a revisit frequency of 6 day. In this study, we investigate the processed Ground Range Detected products at an incidence angle of 39° for the study zone in Vertical-Vertical polarization (C-VV) with a spatial resolution of 10 × 10m. For L-band, we processed Advanced Land Observing System-2 (ALOS-2) data with a spatial resolution of approximately 6 × 6 m and an incidence angle of 32.5° for the study zone in Horizontal-Horizontal polarization (L-HH). To monitor the vegetation dynamic, we calculated the NDVI using already corrected Sentinel-2 data and cloud free selected.

2. METHODOLOGY

To simulate the co-polarized radar signals L -HH and C-VV scattered by pepper-covered fields, we used a modified version of Water cloud Model (WCM). In the context of inter-pixel heterogenous soil water content, the total backscattering $\sigma^0{}_{\mathrm{pepper\_field,pq}}$ is modelled as the sum of the contribution of vegetation row backscattering $\sigma^0_{pepper-row,pq}$ weighted by Fc and the bare soil contribution $\sigma^0_{inter-row,pq}$ weighted by the proportion of bare soil non-covered by peppers (1-Fc) as the following equation :

$$\sigma^0{}_{\mathrm{pepper\_field,pq}} = \mathrm{Fc} * \sigma^0_{\mathrm{pepper-row,pq}} + (1 - \mathrm{Fc})\,\sigma^0_{\mathrm{inter-row,pq}} \quad (1)$$

The contribution of pepper row $\sigma^0_{pepper-row,pq}$ is calculated as the sum of vegetation contribution $\sigma^0_{pepper,pq}$ described by vegetation height (H) and the underlying soil $\sigma^0_{bare-soil,pq}$ attenuated by the vegetation as detailed in the following equation where θ is the incidence angle and A and B are parameters to calibrate and validate depending on SAR sensor parameters and vegetation characteristics.

$$\sigma^0_{pepper-row,pq} = \sigma^0_{pepper,pq} + \tau^2\sigma^0_{bare-soil,pq} \quad (2)$$
$$\tau^2 = \exp(-2 * B * H * \sec\theta) \quad (3)$$
$$\sigma^0_{pepper,pq} = A * H * \cos\theta * (1 - \tau^2) \quad (4)$$

The underlying soil backscattering is the total response of two bare soil parts: drip irrigated part and non-irrigated part. The bare soil contributions are calculated using the modified Integral Equation Model (IEM-B). Due to the limited data, the calibration and validation of the proposed model is performed through three-fold cross validation method.

3. RESULTS

Using co-polarized SAR signals, the modified WCM was calibrated and validated where Root Mean square (RMSE) of 1.26 dB and 1.54 dB for C-VV and L-HH data, respectively. To analyze the behavior of the calibrated model under different conditions of soil moisture values and vegetation parameters, we simulate the SAR data under pepper height ranging from 0.1 to 0.7 m, and vegetation cover fraction ranging from 0.1 to 0.6, underlying soil moisture ranging from 10 to 40 vol.%, and bare soil moisture varying between 5 and 40 vol.% with constant values of roughness to minimize its impact on signal (root mean square of height = 0.8 cm and correlation length = 5 cm). The analysis consists into fixing one condition for example the cover fraction, vary the others (soil moisture, pepper height) and we record the sensitivity of simulated SAR signal as function of the calculated soil moisture per field.

According to figure 2, we scatterplot the slope of the established linear relationships of simulated radar signal as function of soil moisture under low vegetation cover fraction equal to 0.1, three contexts of soil moisture (5, 20 and 40 vol.%) and vegetation height values varying between 0.1 and 0.7 m. For vegetation height equal to 0.1 m, the model sensitivity varies between 0.17 and 0.03 dB/vol.% using C-VV data and between 0.25 and 0.05 dB/vol.%, where the inter-row soil moisture fluctuates between 5 and 40 vol.%. When the vegetation height reaches 0.4 m, under low soil moisture (5 vol.%), the model sensitivity decreases to 0.11 and 0.02 dB/vol.% using L-HH and C-VV data, respectively.

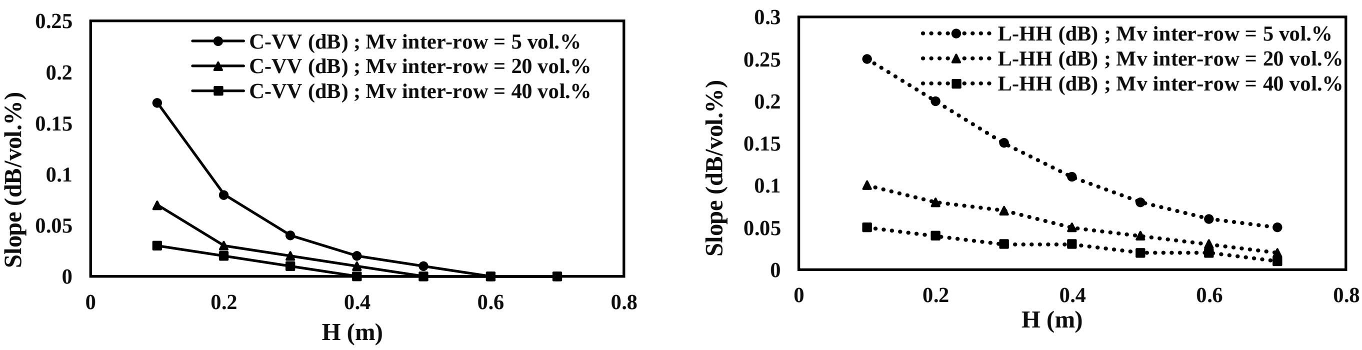

Figure 2. Evolution of the modified water cloud sensitivity to water moisture as function of pepper height under three contexts of inter-row soil moisture (5, 20 and 40 vol.%) using (a) C-VV Sentinel-1 data and (b) L-HH ALOS-2 data.

At the maximum of pepper height (H = 0.7 m) and low soil moisture, the model lost its sensitivity to soil moisture using Sentinel-1 data and decrease to 0.05 dB/vol.% using ALOS-2 data. Under high value of soil water content equal to 40 vol.%, the model using L-HH is insensitive to soil moisture. By increasing the value of fraction cover to 0.6, we noticed the same trends of decreases as function of the increase of inter-row soil moisture and pepper height values. Globally, we observe that model sensitivity decreases as function of the increase of soil moisture and the vegetation development by the increase of the pepper height. This decrease may be indicating the domination of bare soil the total backscattering mechanism until the vegetation backscattering contribution increases at a pepper height equal to 0.3 m for the C-VV signal and 0.5 m for the L-HH signal. The comparison of the two SAR data highlight that the model remains more sensitive to soil moisture using L-band data than the C-band.

4. CONCLUSIONS

In this study, we investigated of the modified WCM sensitivities to soil moisture using L - and C-bands. This examination revealed that model sensitivity decreases as function of the increase of pepper parameters (Cover fraction and vegetation height). The modified WCM becomes insensitive using C-VV data more rapidly than in L-HH case as function the vegetation parameters and soil moisture contexts. The aforementioned results highlight the potential of the modified WCM to simulate radar signal over heterogenous soil moisture contexts using co-polarized SAR data. To estimate the soil moisture, several algorithms are solicitated to apply due to the complexity of the proposed model.

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REFRENCES

[1] L. Santos, T. Oweis, and A. Zairi, "Irrigation management under water scarcity," vol. 57, 2002.

[2] Z. Amiri, M. Gheysari, M. R. Mosaddeghi, S. Amiri, and M. S. Tabatabaei, "An attempt to find a suitable place for soil moisture sensor in a drip irrigation system," *Inf. Process. Agric.*, no. pp. 1–12, 2021, doi: 10.1016/j.inpa.2021.04.010.

[3] Z. Amiri *et al.*, "Remote sensing of irrigated agriculture: Opportunities and challenges," *Remote Sens.*, vol. 97, no. 9, pp. 2274–2304, 2021, doi: 10.3390/rs2092274.

[4] C. Massari *et al.*, "A review of irrigation information retrievals from space and their utility for users," *Remote Sens.*, vol. 13, no. 20, pp. 1–26, 2021, doi: 10.3390/rs13204112.

[5] S. Bousbih, M. Zribi, M. El Hajj, and N. Baghdadi, "Soil Moisture and Irrigation Mapping in A Semi-Arid Region , Based on the Synergetic Use of Sentinel-1," *Remote Sens.*, p. 22, 2018, doi: 10.3390/rs10121953.

[6] M. A. Karam, A. K. Fung, and Y. M. M. Antar, "Electromagnetic Wave Scattering from Some Vegetation Samples," *IEEE Trans. Geosci. Remote Sens.*, vol. 26, no. 6, pp. 799–808, 1988, doi: 10.1109/36.7711.

[7] M. W. Whitt and F. T. Ulaby, *Radar response of periodic vegetation canopies*, vol. 15, no. 9. 1994.

[8] N. N. Baghdadi, M. El Hajj, M. Zribi, and I. Fayad, "Coupling SAR C-Band and Optical Data for Soil Moisture and Leaf Area Index Retrieval over Irrigated Grasslands," *IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens.*, vol. 9, no. 3, pp. 1229–1243, 2016, doi: 10.1109/JSTARS.2015.2464698.

[9] S. Bousbih *et al.*, "Potential of sentinel-1 radar data for the assessment of soil and cereal cover parameters," *Sensors (Switzerland)*, vol. 17, no. 11, 2017, doi: 10.3390/s17112617.

[10] M. El Hajj, N. Baghdadi, M. Zribi, and H. Bazzi, "Synergic use of Sentinel-1 and Sentinel-2 images for operational soil moisture mapping at high spatial resolution over agricultural areas," *Remote Sens.*, vol. 9, no. 12, pp. 1–28, 2017, doi: 10.3390/rs9121292.

[11] N. Ouaadi *et al.*, "Monitoring of wheat crops using the backscattering coefficient and the interferometric coherence derived from Sentinel-1 in semi-arid areas," *Remote Sens. Environ.*, vol. 251, no. August, p. 112050, 2020, doi: 10.1016/j.rse.2020.112050.

[12] M. Zribi *et al.*, "Soil surface moisture estimation over a semi-arid region using ENVISAT ASAR radar data for soil evaporation evaluation," *Hydrol. Earth Syst. Sci.*, vol. 15, no. 1, pp. 345–358, 2011, doi: 10.5194/hess-15-345-2011.