COMPARISON OF X AND C BAND SATELLITE RADAR IMAGES TO CHARACTERIZE IRRIGATED AGRICULTURAL FIELDS

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ABSTRACT

Despite the effect of water content on radar backscattering is well known, isolating the contributions from soil, vegetation, and vegetation superficial water content (wetness) is still challenging. This work aim to characterize the backscatter response over maize crops in the Argentine pampas with differing soil and vegetation water content and wetness considering multipolarimetric X and C band radar. Two images (RADARSAT-2 and TerraSAR-X) were acquired with a 20' time difference over the same study area. Simultaneously with acquisitions, field measurements of superficial soil moisture, dry and wet vegetation biomass and height were performed over irrigated and non irrigated and standing and non emerged crop fields. Soil moisture showed high r^2 for backscatter and several polarimetric decompositions approaches. On the contrary low correlation was found for maize crop growth parameters. X and C band radar indexes seem to saturate at low maize biomass values but could be associated to superficial crop wetness.

Index Terms— SAR soil moisture vegetation water

1. INTRODUCTION

The ability to monitor the water status of a piece of land is among the most frequently cited utilities of radar remote sensing. The advantages of radar systems stem from the use of microwaves which minimize interactions with atmospheric constituents and, -depending on the wavelength among other factors- may provide information on moisture content and roughness not just from the top layer of the objects being observed (e.g. soils or vegetation). Approaches to isolate the effects of moisture content on radar retrievals from those of surface roughness range from change detection techniques to the inversion of empirical, semiempirical or theoretical scattering models [1],[2],[3]. New radar satellites have multipolarimetric capability and are expected to describe better the backscattering mechanisms that occur in soil-plant systems at global scale.

Despite these advantages, operational applications of SAR data to estimate vegetation or soil water content are scarce [4], [5]. Limitations imposed by lack of multiple frequency and polarization images and adequate field measurements have, in part, retarded our understanding on the complex interactions between microwaves, soils and vegetation. We here capitalize from a 20' difference between TerraSAR-X and RADARSAT-2 passes over irrigated and non irrigated fields with emerged and non emerged crops in the Pampas region to assess its ability to estimate i) superficial soil moisture content (from bare and vegetated areas), ii) vegetation water content and biomass, and iii) vegetation wetness.

2. METHODOLOGY

X and C band satellite RADAR images were acquired on 5th January, 2012 over the study area within an interval of 20 minutes (Table 1). Images were calibrated and orthorectified. Polarimetric decompositions were performed using PolsarPro software [6]. For TerraSAR-X (Dual Pol), Cloude-Pottier decompositions were done, generating 3 additional bands: Alpha, Anisotropy and Entropy (Cloude entropy). Entropy was also estimated using the Shannon method (Shannon Entropy). The Freeman-Durden decomposition was additionally performed for the Quad Pol RADARSAT-2 image, generating three more bands related to Surface, Volume and Double Bounce backscattering.

Table 1. Description of images acquired on 5th January, 2013.

Satellite	Acquisition time (UTM)	Mode	Incidence angle	Pixel size (m)
TerraSAR-X	22:31:48	Dual (HH,VV)	31.6°	2.43
RADARSAT-2	22:49:39	Fine Quad Pol	41°	7.22

The study area is located in an agricultural area of the Pampas region (San Antonio de Areco department, Buenos

Aires Province, Argentina - 34º 14'S 59º 33'W). Maize in this area is generally sowed over no till systems at the beginning of October although during the last years late maize sowings occur in December. Field measurements were performed within 3 hours from image acquisitions over 9 agricultural fields (including early and late maize and non emerged crop fields, irrigated and non-irrigated) (Figure 1). Superficial gravimetric soil moisture (0-5 cm depth) samples were taken for each field. Measurements over maize fields included: fresh and oven dry crop biomass and height. Vegetation Water Content (VWC) was also calculated as the difference between wet and dry biomass. On irrigated fields, measurement sites were located along a gradient of increasing time since pivot pass. We examined the relationship between soil moisture content, VWC, maize dry weight and maize height and HH and VV backscatter coefficients and polarimetric indexes obtained from TerraSAR-X and RADARSAT-2 images by means of simple linear regression. Results were compared based on the coefficient of determination of the regressions.

3. RESULTS

There was substantial soil moisture variability among as well as within fields (mean values ranging from 5 to 24 %). Differences in dry biomass and VWC were also high comparing early vs. late sowing dates and irrigated vs. non irrigated maize fields (dry weight ranging from aprox. 1.3 to 14.7 Tn ha-1). However, when considering irrigated fields only, VWC remained very similar.

Table 3 shows the determination coefficients between superficial soil moisture and RADAR derived indices for maize and non vegetated fields. As expected, soil moisture showed higher r^2 for TerraSAR-X and RADARSAT-2 at bare soil. RADARSAT-2 showed in general higher r^2 values than TerraSAR-X. For both platforms, Cloude decomposition indexes did not show correlation with soil moisture, but Shannon Entropy showed high r^2, even higher than σ^0. For RADARSAT-2 Freeman-Durden decomposition showed the highest r^2 values for the surface component at bare soil, while the highest r^2 value over maize crops was found for the volumetric component.

When analyzing crop growth variables, both satellites showed lower r^2 values than those found for soil moisture (Table 4). In general, correlation was higher for VWC than for dry weight or height although in absolute terms relationships were weak. Highest r^2 values were found for σ^0 VV and Shannon Entropy.

4. DISCUSSION

These results show that X and C band polarimetric data is useful for soil moisture estimation but have limited capacity for maize monitoring. Shannon entropy showed acceptable r^2 –e.g. 0.60 and 0.80- for bare soil moisture content. In [7] and [8] is shown that entropy could be associated to vegetation biomass. Similarly entropy can be related to soil moisture

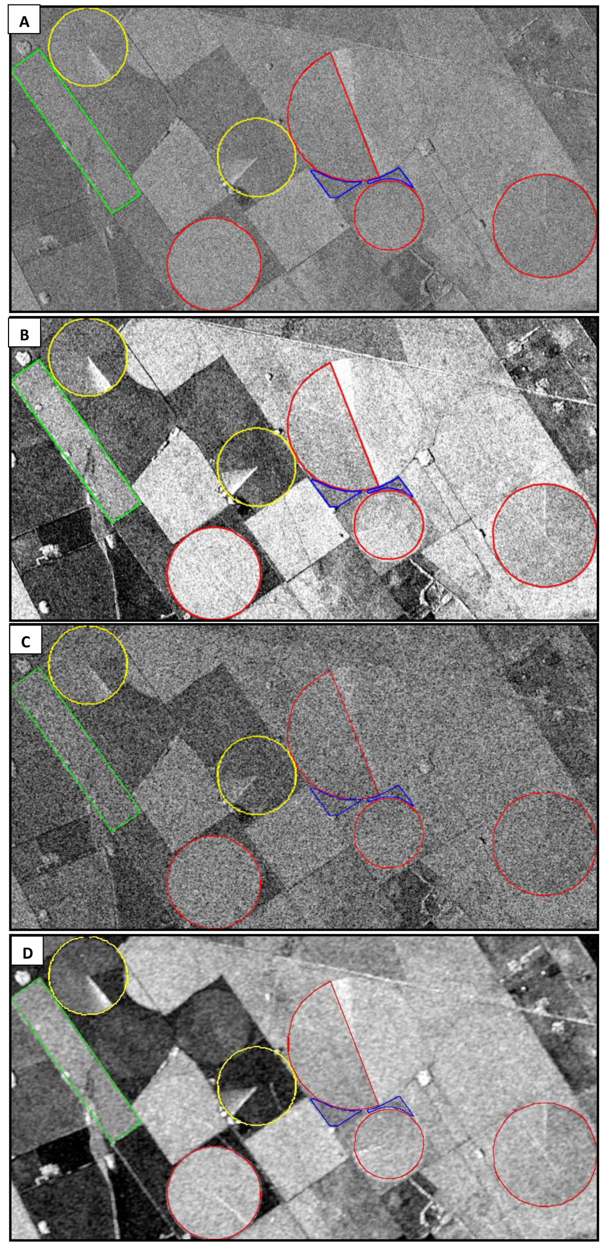

Figure 1. A) TERRASAR-X σ^0 HH polarization acquired on January 5, 2012 22:31:48. B) Shannon Entropy decomposition from TerraSAR-X. C) RADARSAT-2 σ^0 HH polarization acquired on January 5, 2012 22:49:39. D) Shannon Entropy decomposition from RADARSAT-2 .Red: Irrigated Maize fields; Blue: Non Irrigated Maize; Green: Non Irrigated Late Maize; Yellow: Not emerged crop fields.

since it becomes near zero for smooth land surfaces and increases with dielectric constant of the medium [9]. In this case, for both satellites, Shannon entropy improved the contrast among non irrigated (smooth no till land), partially irrigated and full irrigated as observed in Fig. 1. The higher r^2 obtained between soil moisture and RADARSAT-2 rather than TerraSAR-X could be associated to the higher penetration depth expected at longer wavelengths, in particular considering that a soil samples were taken up to a depth of 5 cm.

Despite an almost 10-fold increase in maize dry weight no clear relationship emerged suggesting that X and C bands may saturate at low dry weights. We recognize that factors other than dry weight might have affected the radar signal. However, we assume that leaf size and orientation variability must have been limited as we only considered maize fields. Additionally, as fields were under a non-tillage regime surface roughness variability between early and late maize fields must have remained low. Canopy structure, however, differs between early and late maize as the former accommodate the majority of its aboveground biomass on larger and higher stalks while in the latter distributes it biomass more equally between shorter stalks and leaves. In any case, the effect of different canopy structures must have been reduced as suggested by the low r^2 obtained for the relationships between dry weight and any index.

Table 3. Determination coefficients between gravimetric soil moisture (0-5 cm) and several RADAR index derived from TerraSAR-X and RADARSAT-2 images measured over not emerged crops and over maize fields.

Satellite	Radar index	Bare soil	Maize
TerraSAR-X	σ^0 HH	0.35	0.34
	σ^0 VV	0.42	0.21
	Alpha	0.03	0.00
	Anisotropy	0.00	0.00
	Cloude Entropy	0.00	0.00
	Shannon Entropy	0.62	0.48
	number of observations	34	40
RADARSAT-2	σ^0 HH	0.55	0.12
	σ^0 VH	0.38	0.06
	σ^0 VV	0.55	0.28
	Alpha	0.08	0.00
	Anisotropy	0.00	0.00
	Cloude Entropy	0.10	0.05
	Shannon Entropy	0.80	0.50
	Freeman Durden Surface	0.70	0.04
	Freeman Durden Volumetric	0.54	0.29
	Freeman Durden Double Bounce	0.31	0.01
	number of observations	34	40

Intriguing, Shannon entropy retained some association with soil moisture at vegetated fields as suggested by r^2 between 0.2 to 0.5. Taking into account the apparent low saturating threshold for biomass, we speculate that the radar response could be due to the presence of superficial wetness at irrigated maize fields. Plant superficial wetness is unavoidably associated to high superficial soil moisture when irrigation is performed with pivots –that sprinkle from above- as it was in our study. Indeed, the set of parameters

Table 4. Determination coefficients between measured variables over maize fields (Crop Height, Dry weight and Vegetation Water Content) and several RADAR index derived from TerraSAR-X and RADARSAT-2 images.

Satellite	Radar index	Crop Height	Dry Weight	VWC
TerraSAR-X	σ^0 HH	0.14	0.12	0.13
	σ^0 VV	0.16	0.12	0.19
	Alpha	0.00	0.00	0.00
	Anisotropy	0.01	0.00	0.00
	Cloude Entropy	0.01	0.00	0.00
	Shannon Entropy	0.18	0.16	0.23
	number of observations	39	40	40
RADARSAT-2	σ^0 HH	0.05	0.03	0.05
	σ^0 VH	0.05	0.06	0.05
	σ^0 VV	0.18	0.16	0.25
	Alpha	0.01	0.01	0.00
	Anisotropy	0.00	0.00	0.00
	Cloude Entropy	0.12	0.11	0.13
	Shannon Entropy	0.16	0.15	0.23
	Freeman-Durden Surface	0.02	0.03	0.01
	Freeman-Durden Volumetric	0.15	0.15	0.16
	Freeman-Durden Double Bounce	0.02	0.01	0.01
	number of observations	39	40	40

derived by Freeman-Durden decomposition shows that the volumetric component had the highest –albeit low- r^2 for vegetated fields, suggesting that maize biomass contribution was important. On the contrary, the superficial component showed highest correlation with soil moisture content under bare soil conditions, showing that single bounce scattering mechanisms dominate when vegetation is absent or scarce.

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