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Assessment of SAR polarimetry for crop monitoring in the Argentinean Pampas Plain

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Background

On-going and near-future Synthetic Aperture Radar (SAR) satellite missions are expected to provide meaningful and timely information over vast agricultural lands such as that of Argentinean Pampas Plain, leading to actual economic benefits regarding to seeding dates, irrigation strategies and crop yield forecasting, thus contributing to food security efforts. The Argentinean SAOCOM (www.conae.gov.ar/eng/satelites/saocom.html) mission have been specifically designed to monitor croplands, exploiting its full polarimetric capabilities at L-band (λ=23cm). This mission will is scheduled for launch in 2016. Moreover, with the add-on of the ESA's passive Companion Satellite (SAOCOM CS), bistatic measurements will be available for a number of agricultural-related research activities.

The potential of SAR observation systems for classification of agricultural crops, monitoring of crop biomass, and measurement of soil moisture has been recognized for a long time. It is well documented that the development of crops over time leads to changes in backscatter [Skriver 1999, McNairn 2004, Soria-Ruiz 2007, Wang 2010, Kim 2013]. Moreover, it is suggested that the important scattering mechanisms when dealing with agricultural areas are direct backscatter from bare soil/underlying ground, direct backscatter from the plant components (leaves, stems, fruit), double-bounce backscatter between the soil surface and crop canopy, and in some cases ground-vegetation-ground and multiple scattering mechanisms [Skriver 1999, Adams 2013]. These scattering types can be heavily influenced by the incidence angle and temporal conditions. For many surfaces, the backscatter decreases with an increasing incidence angle as shallow angles result in specular reflection. However, when considering vegetation, a shallow angle may result in diffuse backscatter from the canopy, whereas a steep incidence angle would be more typical of surface scattering from the soil or canopy components [Brisco 1998]. The research suggests that when seeds are still below the surface, the main contributor to a radar response is single-bounce backscatter due to the rough, plowed state of the soil as well as moisture content of the soil [Kim 2009]. As plant elements emerge and begin to develop, both the co-polarized and cross-polarized backscatter intensities tend to increase. The increase in co-polarized backscatter is due to a combination of single bounce backscatter directly off leaves or stems, etc. and soil-vegetation double-bounce backscatter, whereas the cross-polarized backscatter is amplified by volume scattering influenced by the crop canopy. One way to discriminate between the surface and double-bounce is to use the co-polarized phase difference. Further analysis of the scattering matrix can be performed on polarimetric data in order to extract fundamental detail about the scattering process across the image [Montero 2011, Kim 2013].

An important property of microwaves is their capability to penetrate into the media. Over natural targets, the volume under consideration does not present a homogeneous dielectric constant. The presence of inhomogeneities within the volume makes it possible to have backscattered energy from within the volume. This is the reason why microwaves are considered for the study of volumetric targets. The most apparent example of this backscattering mechanism appears when the radar system images vegetated areas. The backscattered energy is returned from the upper layer of the canopy, but also from the multiple targets (leaves, branches, trunk and even the ground beneath the canopy) that conform the different vegetation layers. On the one hand, the properties of the backscattered energy depend on the dielectric constants of the different elements that form the volume where water content (both in the soil and in the vegetation) plays a crucial role. On the other hand, the backscattered energy shall also depend on the dimensions of the different components of the volume, on their internal arrangement and on the roughness of soil surface beneath.

As it has been mentioned, the wave scattering process from random media depends on electromagnetic factors related to the scatterer itself, as for instance: composition, conductivity, permittivity, geometrical arrangement, but also on factors determined by the illuminating wave [Ualby 1986, Ulaby 1990]: frequency, polarization or incidence angle.

The electromagnetic factors mentioned have a biophysical counterpart: soil and vegetation water content, structural and orientation properties, soil texture, among others. Polarimetry has the potential to serve as linkage between those two groups, for a certain set of illuminating parameters. ***Thus, relating electromagnetic parameters to biophysical ones through polarimetry enables the monitoring of croplands by microwave polarimetry remote sensing. This is the underlying working hypothesis of this proposal.*** Current capabilities of JAXA ALOS-2 enables to set-up and perform dedicated field experiments for the development of application examples that point out the important role polarimetric information plays in qualitative and quantitative SAR remote sensing applications.

Objective

This study contributes to the following objectives:
- To evaluate the performance of PolSAR data for agricultural monitoring based on a time series, i.e. multitime & multiple incidence angle, at L-band.
- To extend the actual background knowledge gained at C-band and to assess the added value of polarimetry for agricultural monitoring at L-band

The first objective is based on the physical interpretation of the scattering process by analyzing both the scattering mechanisms and the intensity of the backscatter response.
The second objective is relevant due the acquisition schedule for ALOS-2, which have a number of limited operating modes. Most of the planned acquisitions will be on dual polarization mode instead of on quad polarization mode. This sets the need for studying the suitability of coherent dual polarization modes for the analysis and characterization of agricultural areas [Cloude 2007].

Significance in the research field

By means of the useful information carried on the full-polarization SAR data, polarization decomposition theory and its application have become the hot spot in the domain of radar remote sensing. Polarimetry has been demonstrated as an important system property that helps to improve the extraction of geophysical and biophysical information. Since polarization decomposition theory may distinguish the different types of scattering mechanisms, it offers a new solution to investigate croplands by remotely-sensed observations. However, literature on polarimetric radar remote sensing of croplands has been traditionally focused on classification and change detection.

Research on monitoring crop grown cycle using the added advantages of polarimetric observations is scarce. Studies were focused mainly on rice paddy fields where harvest detection and plant phenology [Lopez-Sanchez, 2011] has been explored. The underlying water surface in paddy fields leads to rice scattering mechanism being very different from other ground objects. However, scattering mechanism for other crops without a smooth underlying water surface are much more difficult to elucidate. Previous literature of polarimetric (C-band) RADARSAT-2 data has primarily focused on mapping targets with less emphasis on how these targets actually interact with the SAR [Shang 2011, Vaglio 2013, McNairn 2009, Liu 2013].

Moreover, state-of-art soil moisture retrieval algorithms [Kim 2009, Barber 2015] require precise input model parameters corresponding to vegetation and soil, since uncertainties on these model parameters often leads to not sufficiently accurate retrieved estimates to meet scientific requirements [Walker 2004].

Methodology

1. Area selection

Advantage on current research at San Antonio de Areco study site (Fig. 1) is taken. The study site spans an area of about 70x70 km in northern Buenos Aires province, Argentina (center coordinates 34° 15′ 43″ S/59° 28′ 0″ W), that is one of the Joint Experiment for Crop Assessment and Monitoring (JECAM) sites (http://www.jecam.org/).

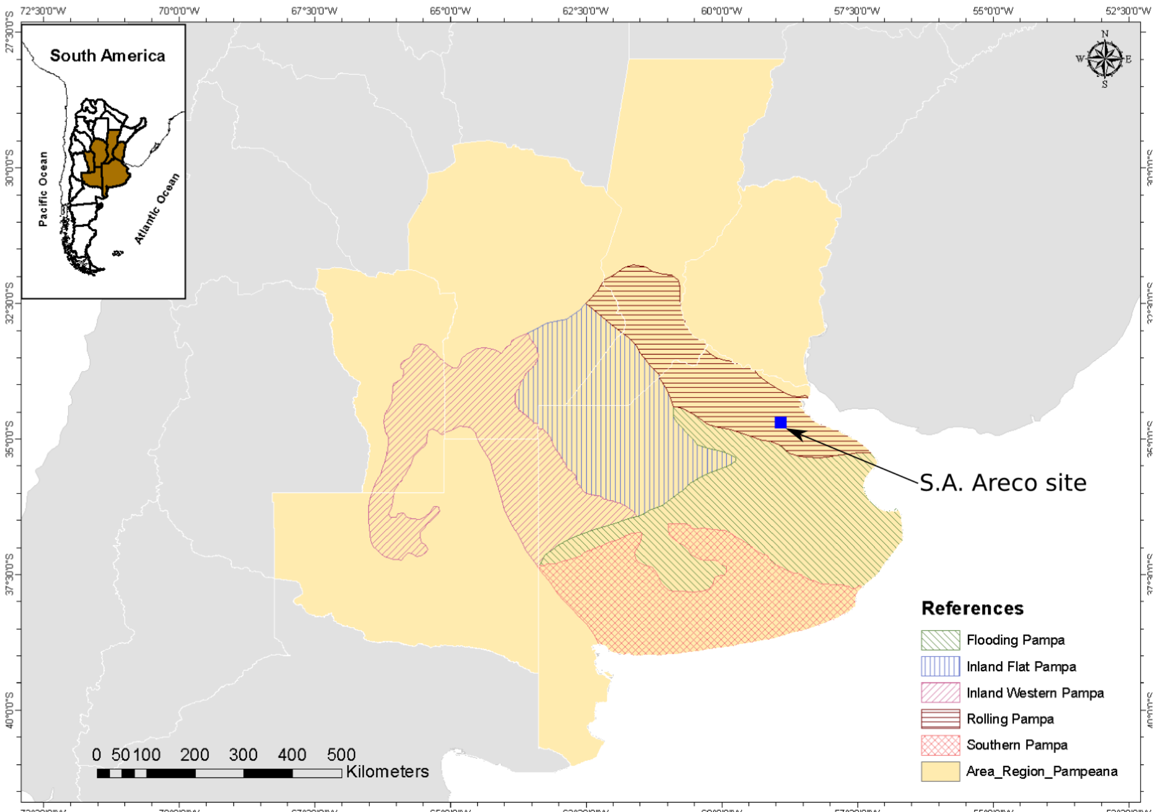

Figure 1: The study site and its geographic situation in relation with the regions encompassing Pampas Plain.

San Antonio de Areco study site belongs to the Argentine "Pampas" (Ecoregion: Rolling Pampa) at ~100 Km of Buenos Aires City. The area has a mild (temperate)-subhumid climate (1000mm mean annual rainfall) with the following features:

- Typical Field Size (Area): 20-30 hectares.
- Farming practice: Mostly rain-fed, with a few irrigated fields.
- Main Crops: Soybean, wheat and maize.
- Crop Growing Season:
  - Soybeans, from November to June.
  - Wheat, from June to February.
  - Maize, from August to June.

- Soil type: Typical Argiudoll, with a well-developed B horizon.
- Soil Texture: Silty loam soils (silt content of 60-70%) up to 30 cm depth. From 30 cm depth, the textural B horizon is silty clay loam.
- Landscape Topology: Almost flat to undulating plains with slopes lower than 2% to 3%.
- Soil Drainage Class: Poor to imperfectly drained.

Field work is planned in several sites within the district (See Fig. 2). With the presence of an extensive agricultural activity, the area provides an ideal location for analyzing polarimetric properties of agricultural targets.

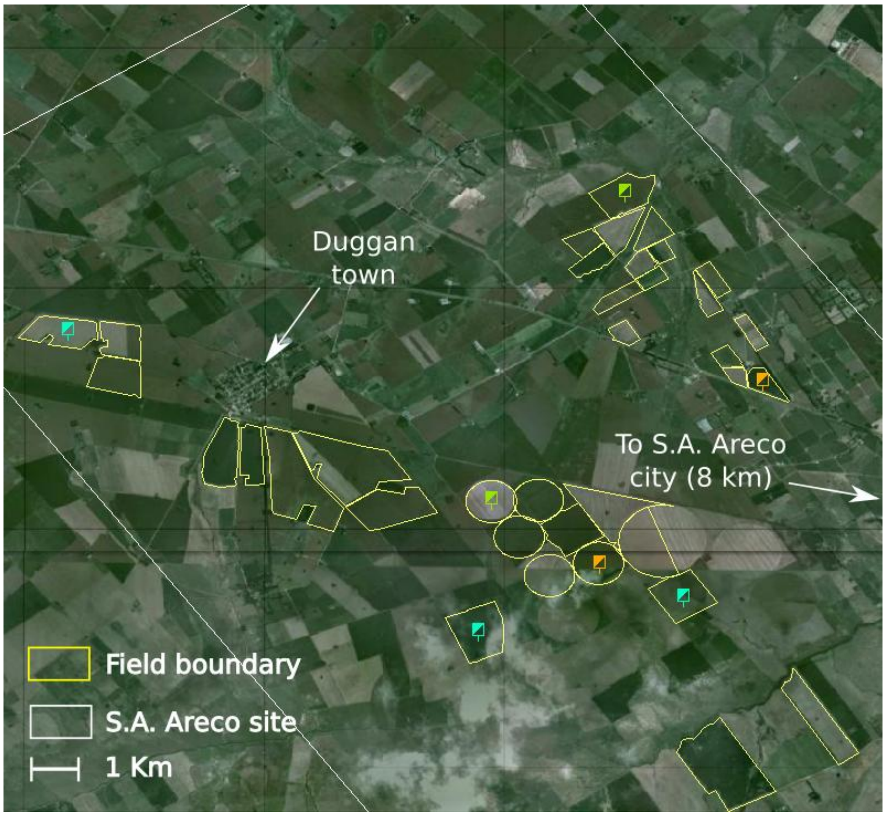

Figure 2: The city of San Antonio de Areco (not shown) and the town of Duggan with the bounded fields encompassed a 70 km x 70 km study site. The main crops are soybeans, wheat and maize.

2. Target decomposition

Algorithms known as target decomposition theorems have been developed to identify the individual scattering components of the target. Two of the more commonly used decomposition theorems include the Freeman-Durden and the Cloude-Pottier decompositions, which will be used here. The Freeman-Durden decomposition employs the coherency matrix to break down the data into three scattering types: surface, double-bounce and volume [7,8]. Using this mathematical procedure, the percentage of each mechanism contributing to each individual pixel is determined [6]. In other words, a weight for each scattering method is applied. The alternative, the Cloude-Pottier decomposition, produces three parameters: entropy (H), alpha angle (α), and the less commonly used anisotropy (A). Entropy is defined as the disorder (i.e., randomness) of scattering mechanisms of a pixel and in this work is normalized to range from 0 (pure scatterer) to 1 (multiple scatterers) [6,9]. The alpha angle identifies the dominant scattering mechanism as surface ($\alpha<40°$), volume (40°–50°) and multiple (double-bounce) scattering ($\alpha>50°$). Anisotropy estimates the importance of secondary scattering mechanisms and also has a range between 0 and 1.

3. Growing cycle analysis

Analysis will be carried out for each crop separately, leading to different time series. For each time series, decomposition parameters will be interpret in terms of phenology and structure of the crop, and soil moisture and roughness.

Algorithm to be used

Decomposition of SAR images will be perform using our dedicated scripts written in MATLAB, after pre-processing in ESA's NEST and ENVI.

Anticipated results

The different results reported in the literature demonstrate that the use of polarimetry clearly outperforms classification techniques based only on intensity (i.e. no phase information) quad-polarized SAR images. Thus, it is expected that polarimetry applied to polarimetric images also allows the quantitative extraction of physical parameters concerning vegetation and soil parameters of croplands.

A previous study conducted by Montero et al. [Montero 2011] over a time series of RADARSAT-2 PolSAR data over agricultural areas states that polarimetric data presents a clear added value with respect to single polarization data, for the analysis and characterization of agricultural areas. Based on this study, it is expected that polarimetric information at longer wavelength (L-band) be more sensitive to the geometrical structure of the crops for multi-time acquisitions and more correlated with surface soil moisture, due to its better ability to penetrate the canopy than C-band. It is also expected a small variation of polarimetric information w.r.t. the incidence angle for multiple incidence angle acquisitions. And finally, as for quad polarisation vs. dual polarisation operating modes, it is expected that coherent dual polarization modes are also suitable for the analysis and characterization of agricultural areas, with the combination VV-VH more suitable than HH-HV.

Kind of truth data and its acquisition plan (Area, Product level, Volume, Term, Season, etc.)

Field work is planned throughout the growing cycle (from June to April) in several sites within the JECAM San Antonio de Areco study site. Low variability parameters, such those of the vegetation will be measured according to founding resources. High temporal variability parameters, such as soil moisture, will be measured the same day of the acquisitions.

The following variables will be measured:

1. **Soil moisture**: Using dielectric probes at 10 cm depth. Two complementary methodologies will be used: (a) meteorological stations and (b) mobile measurement devices. The first implementation was developed to characterize soil moisture of a specific site in a systematic way, (every ~30 min). Other relevant agro-meteorological variables are also measured simultaneously for completeness. The second implementation is designed to characterize the spatial variability of soil moisture at field scale. To this end, a soil moisture dielectric probe (Hydra Probe II, http://www.stevenswater.com) and a GPS receiver were integrated via Bluetooth with a Tablet using *ad hoc* software. Surveys using mobile devices will be carried out in coincidence with

acquisitions. Both stationary and mobile sensors are systematically cross calibrated with gravimetric measurements by means of the oven-heated method.

2. **Soil roughness:** Roughness condition will be assessed by visual inspection and compared to tables.

2. **Other variables and/or properties**: Soil temperature will be also determined simultaneously with soil moisture measurements.

3. **Vegetation parameters**:

1. Crop type for discriminating among crops (soybean, wheat, maize, sunflower).
2. Plant density, plant spacing, row direction, interrow spacing, (will be measured in selected wheat and soybean plots).
3. Plant height (measurements of maximum height -top of the canopy- with a rigid meter in selected wheat and soybean plots).
4. Crop biomass (plant harvests and measurement of dry weight at selected wheat and soybean plots).

All these vegetation parameters will be measured as part of the JECAM site requirements

Product Utilization Plan (Product level, Volume, Term, Season, etc.)

PALSAR-2 StripMap Ultrafine/High-Sensitive/Fine Dual Mode (HH/HV) over the study site (s) from January 2016 to December 2017. Processing level: 1.1 (SLC).

PALSAR-2 StripMap High-Sensitive/Fine Full Mode (HH/HV/VH/VV) over the study site (center coordinates 34° 15′ 43″ S/59° 28′ 0″ W) from January 2016 to December 2017. Processing level: 1.1 (SLC).

Work plan

The foreseen tasks will be the following:

1. Requesting for SAR data (ALOS-2/PALSAR-2).
2. Field campaign for the acquisition dates.
3. Satellite data preprocessing (area of interest data extraction, etc.)
4. Developing and implementation of polarimetric decompositions for every field with available ground-truth.
5. Sensitivity assessment of the polarimetric parameters to ground-truth data.

Task/Semester	1st Semester	2nd Semester	3rd Semester	4th Semester
1	x	x	x	x
2	x	x	x	x
3	x	x	x	x
4	x	x	x	
5			x	x

Data processing and analysis equipment

The institute for Astronomy and Space Physics (IAFE, www.iafe.uba.ar/tele/) provides full institutional support for the realization of this project by its Remote Sensing Group. IAFE has an extensive record on cooperation with Argentinean Space Program (Fig. 2). The Remote Sensing Group has an office equipped with state of the art computers that are appropriate for the realization of the proposed work plan. It also has the staff and logistical contacts to carry out the fieldwork, with the aid of the National Agricultural Technology Institute (INTA) personnel. When necessary, large amount of data and model simulations can be processed onto a cluster at IAFE.

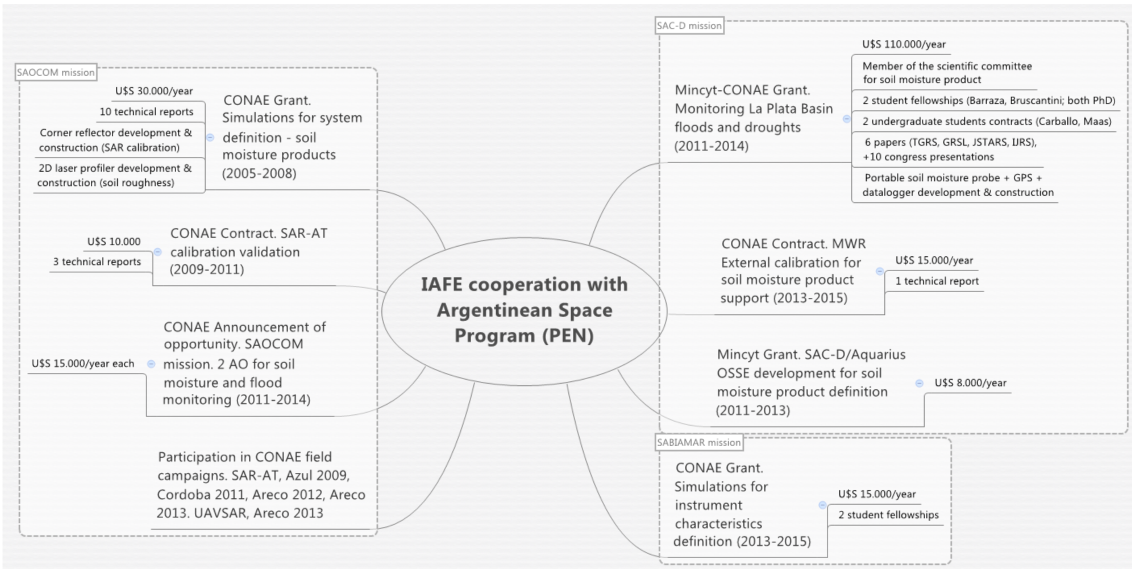

Figure 3: Cooperation network between IAFE and CONAE. Note the items under SAOCOM mission.

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