MONITORING INUNDATION DYNAMICS IN PARANÁ RIVER, ARGENTINA, BY C AND L BAND SAR

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ABSTRACT

This paper analyses the SAR response of wetland ecosystems under different environmental conditions and at two different frequencies. We exploited the opportunity of observing the same inundation phenomena by two currently available SAR systems, such as ENVISAT ASAR (C band) and ALOS PALSAR (L band). The results obtained for C band are similar to the ones reported previously in the same area. Increasing water level in marshes is characterized by an increase and then a decrease in the backscattering coefficient of vegetation. An increase when water level changes the soil from saturated to flooded condition and a decrease when the water covers the vegetation. The new ALOS PALSAR L Band results shows that in marshes, the increase in water level is seen as a decrease in the backscattering coefficient, since the reduction of emerged biomass reduces the available matter for the wave to interact with.

Index Terms— wetlands, SAR, ALOS PALSAR, ENVISAT ASAR, interaction model simulations,

1. INTRODUCTION

In spite of the recognized importance of wetlands and the large volume of satellite observations available, the potential of satellite techniques to detect inundated wetlands and to quantify their seasonal and spatial dynamics has not yet been systematically assessed. Estimates of water level in vegetated areas are even more difficult to determine and few publications address this complex subject.

This paper analyses the SAR response of wetland ecosystems under different environmental conditions and at two different frequencies. To this aim, we exploited the opportunity of observing the same inundation phenomena by two currently available SAR systems, such as ENVISAT ASAR and ALOS PALSAR.

It is well known that depending on vegetation structure and soil condition, it is possible to observe strong changes in the SAR response. A typical flooded area will be seen dark in the image, but a flooded forest may be observed as a bright target in the same flood event. Combining observations and interaction models, in the following sections we discuss C and L Band behavior for two vegetation structures and two environmental conditions.

2. STUDY SITE: HYDROLOGY AND VEGETATION STRUCTURE

The Paraná River Delta region stretches through the final 300 km of the Paraná river basin, covering approximately 17,500 km^2 [1] and is located between 32º05'S, 60º48'W, and 34º29'S, 58º30'W, close to the city of Buenos Aires. It is a vast macro-mosaic of wetland types, and has a complex hydrological regime determined by the influence of the Paraná and Uruguay rivers and De La Plata estuary.

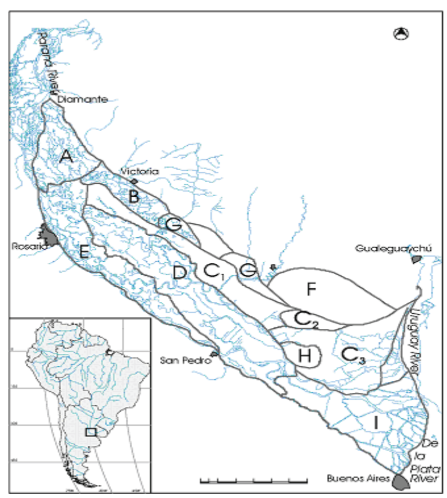

Fig. 1: Location of the Paraná Delta in South America. Landscape units (LUs) from A to I.

Malvárez [2] divided this large region in landscape units characterized by the combination of the geomorphologic setting, the hydrological regime and the complexity of plant communities that result in a high ecological diversity. Figure 1 shows the spatial distribution of these units. A thoroughly description can be found in [2] [3]. Units A, D and E are mainly covered by prairies of floating and rooted plants, open water lagoons and forests; unit F by grasslands and open forests and the lower part, unit C and I, mainly by marshes and forests plantations.

3. COMPARING AND ANALYZING OBSERVATIONS OF C AND L BAND RADARS

Since 2001, the area is being studied through a multiscale-multisensor approach following a top-down/bottom-up methodology in order to analyze heterogeneity and dynamic patterns in the Paraná River Delta region [4]. At regional scale, ENVISAT Wide Swath Mode (WS) imagery (pixel size: 75 m) as well as multispectral SACC MMRS optical images (pixel size: 175 m) were used to identify and map the LUs of the region [11]. At Landscape scale, detailed wetland cover maps were produced for the southern half portion of the region. At wetland cover scale, special effort has been made in the downstream portion of the delta region, in order to study ecosystem functioning of tidal freshwater marshes dominated by *Scirpus giganteus* (*Cortadera* marsh) and *Shaenoplectus californicus* (*Junco* marsh). These marshes cover more than 40% of the Lower Delta surface, in the upper portion of the Del Plata estuary. Furthermore, these species are particularly sensitive to environmental changes, so they are good indicators of wetlands disturbance. At site scale, several ENVISAT ASAR co-polarization (VV HH) images were used to analyze above ground biomass and water below the canopy in both Junco and Cortadera marshes [5][6].

A common, repeated statement is that SAR images are sensitive to wetlands hydrological conditions. This is true in general, but to combine landscape maps with SAR images to obtain inundation dynamics at regional level is not a trivial task. The observed complexity is related mainly to: (1) different spatial resolutions and (2) different radiation/matter interactions.

When trying to combine SAR information with optically derived landcover maps in wetlands characterized by patchy ecosystems, we must take into account that:

1. Inside a single pixel in mid-low resolution SAR images (ScanSar) a multiplicity of scatterers may be present. So, the value of the backscattering coefficient σ^0 of a single pixel can be determined by a single scatterer [7].
2. Inside a particular low resolution landcover map pixel several SAR pixels may be needed to cover the area. In patchy ecosystems, these pixels can potentially belong to different ecosystems, with different scattering behaviors.
3. Different hydrological conditions can be present in neighboring ecosystems.

Acknowledging these facts and the different hydrological condition of the images analyzed, we discuss the SAR response at C and L bands at site specific level and at land cover level (as determined by medium resolution optical images).

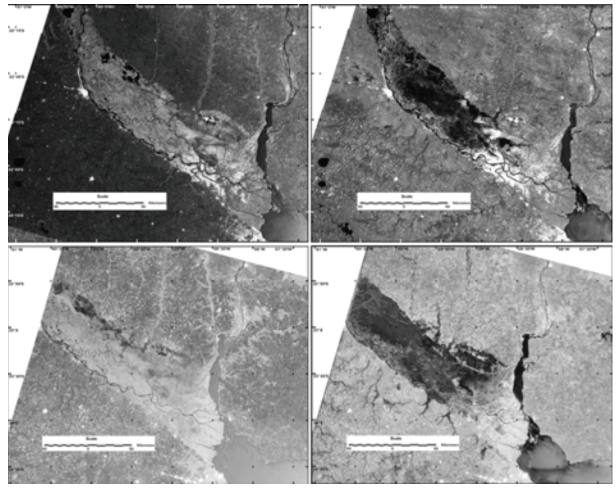

Fig. 2: ENVISAT ASAR WS images corresponding to non-flooded (12/9/05, top left) and flooded (26/3/07, top right) and ALOS PALSAR WB1 images corresponding to non-flooded (31/12/06, bottom left) and flooded conditions (2/4/07, bottom right).

Figure 3 shows the results obtained comparing data extracted from ENVISAT ASAR WS, ENVISAT ASAR Standard S2 (extracted over selected samples [5]) and simulations based on a radiative transfer model and *ad hoc* ground truth [8] [5].

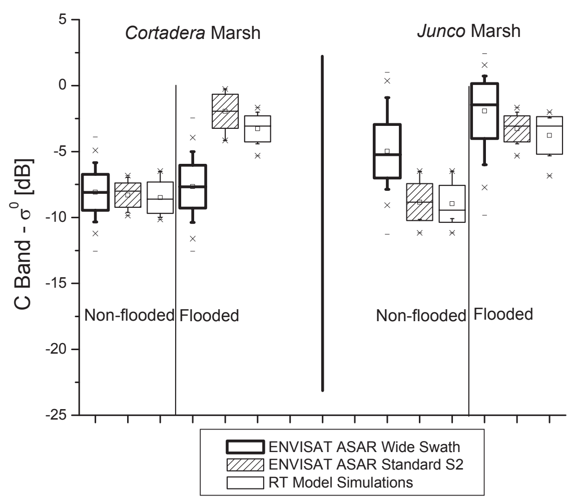

Fig. 3: ENVISAT ASAR WS data, ENVISAT ASAR Standard S2 data [5] and simulations based on a radiative transfer model [8].

Model simulations were carried out using the radiative transfer (RT) model developed in [8], and adapted for herbaceous vegetation in [5] and [6]. In summary, the model is a function that takes as input bio-geophysical variables, and returns the scattering matrix of the ecosystem. The input variables are the bio-geophysical magnitudes that are relevant for the backscattering behaviour of the ecosystem. In the case of herbaceous vegetation, they are leaf area index (LAI), height, shoot radius, leaf width, plant water content (PWC), and plant density. We were unable to measure these variables in the image acquisition dates, but we have previous estimates of their probability density functions. We used this prior statistical information to run a Monte Carlo simulation using the RT model in order to estimate the expected range of σ^0 values.

From left to right, the first group of three box plots show WS, Standard and simulated σ^0 for non flooded *Cortadera* marshes.

C Band image - non-flooded - *Cortadera* marsh: It can be seen from the figure that there is a very good agreement between both SAR data acquisition modes (WS and Standard). This agreement is related to similar phenological and hydrological conditions in both acquisition dates. Also, model simulations present a good agreement with data, a fact already discused in [5].

C Band image - flooded - *Cortadera* marsh: As seen in the figure there is an important difference in σ^0 values between WS and Standard data. This discrepancy is probably related to different hydrological conditions in acquisition dates, since there is strong evidence that by the time ENVISAT ASAR image was acquired (26/3/2007) the Cortadera marsh ecosystem was not flooded [9]. As expected, model simulations agree with Standard data but do not with WS data, since the input variables provided are for the flooded case.

C Band image - non-flooded - *Junco* marsh: The σ^0 values of WS and Standard data differ. This may be also related to different environmental conditions (water level inside the marsh). Model simulation agrees with Standard data, for the reasons provided above.

C Band image - flooded - *Junco* marsh: There is a general agreement between WS data, Standard data and model simulations.

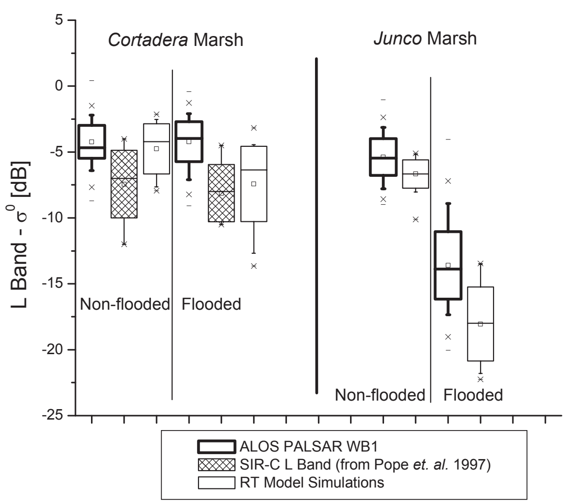

Fig. 4: ALOS PALSAR WB1 data, SIR-C L Band data [10] and simulations based on a radiative transfer model.

Figure 4 shows the results obtained comparing data extracted from ALOS PALSAR WB1, with simulations based on the same radiative transfer model used before. As we have no previous L band σ^0 data acquired over *Junco* or *Cortadera* marshes, we used data from bibliography in order to compare with other acquisitions over similar ecosystems. Since it deals with L Band SAR images acquired over wetlands, in areas where herbaceous vegetation is present, we chose the work of Pope *et. al.* [10]. It is important to note that [10] deals with *Cladium Jamaicense* and *Typha domingenis*, that are structurally similar to *Cortadera* marsh, not to *Junco* marsh.

L Band image - non-flooded - *Cortadera* marsh: There is a good agreement between PALSAR data and model simulations, but the SIR-C L Band data present lower values. There is not enough auxiliary information from both ecosystems to explain this difference, but is important to note that the order of magnitude of the values is similar.

L Band image - flooded - *Cortadera* marsh: A good agreement can be seen between simulated and bibliographical values [10], but PALSAR data are a little bit higher. Again, it is important to note that the order of magnitude of the values is similar.

L Band image - non-flooded - *Junco* marsh: The σ^0 values of PALSAR and model simulations agree. There is no other experimental evidence to compare PALSAR data.

L Band image - flooded - *Junco* marsh: The σ^0 values of PALSAR are higher than model simulations. We believe that this is due to a model sub-estimation of *Junco* marsh σ^0 values at L Band, related to uncertainties on *Junco* plant spatial angular distribution.

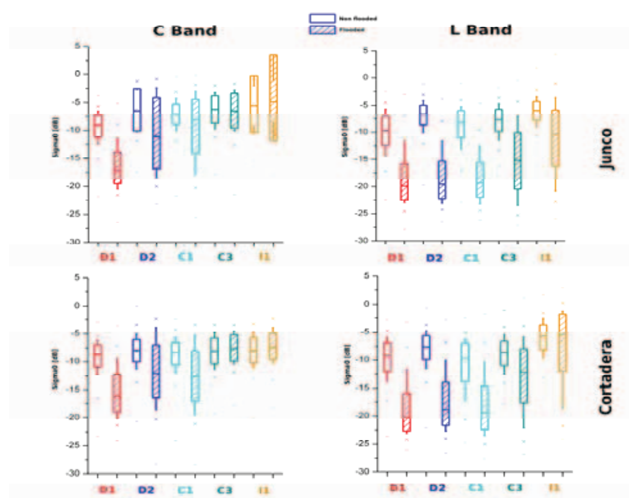

Fig. 5: ENVISAT ASAR WS and ALOS PALSAR WB1 data, extracted from *Junco* and *Cortadera* marshes on the C, D and I Landscape units.

Figure 5 shows box plots of σ^0 values of ENVISAT ASAR WS and ALOS PALSAR WB1 corresponding to landcover map polygons of *Junco* and *Cortadera* marshes [11] for different landscape units (C1, C3, D1, D2, I1)

These box plots have a much higher spread because the landcover polygons, although corresponding to a single vegetation type, cover a large area. The variability is large due to variations in vegetation parameters and in soil condition (hydrology). L Band shows stronger differences between flooded and non-flooded than C Band because the water level was higher [9].

This figure summarizes several combinations of vegetation characteristics and hydrological conditions.

At C Band, *Cortadera* marshes data show one behaviour at D1, D2 and C1 LUs and a different one at C3 and I1. This is due to the fact that D1, D2 and C1 are strongly affected by the Paraná River while C3 and I1 are affected in a lesser way, showing a more stable response. At L Band, *Cortadera* marshes show strong differences between flooded and non-flooded in all landscape units. Heavy rains the week prior to acquisition and the Paraná River in evacuation level explain these differences. A similar argument is valid for *Junco* marshes. The behaviour of C Band for *Junco* marshes may be explained by the variability of water level inside the marsh, from one unit to the other.

4. DISCUSSION OF RESULTS

In studies of large wetlands, a major challenge is to extend the knowledge of a site where field work has been done and inputs to model simulations have been measured to areas where there is little quantitative information available and to large extensions of very similar vegetation structures. In addition, in patchy ecosystems, main rivers, small tributaries, topography and infrastructure (dikes) modify the hydrological behavior of neighboring ecosystems where the same vegetation structure may be present. All this may be seen in radar images, but no easily understood.

Using a land cover map of medium resolution and site specific information about vegetation structure of two wide spread ecosystems (*Cortadera* and *Junco* marshes) of the Paraná Delta, we discussed the responses of C band and L band SARs.

The site specific data show a good agreement with model simulations in both C and L bands. This is encouraging because it demonstrates that models are well suited for both frequencies. The differences between C and L bands in the responses are in part due to the frequencies (relationship between the size of the scatterers and the SAR frequency), but in this case mainly due to the differences in water level between images. Although 2007 images correspond to the same flooding event, strong rains took place in the week difference, inundating new areas as seen in the L band image.

Also, we want to point out the importance of spatial heterogeneity of hydrology and vegetation in SAR responses, when moving from site-specific (figures 3 and 4) to regional scales (figure 5) in wetland studies.

5. ACKNOWLEDMENTS

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