RECENT RESULTS ABOUT ASAR OBSERVATIONS OF WETLAND MARSHES

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ABSTRACT

The paper describes how ASAR observations and electromagnetic models were used to obtain estimates of water level below two marshes with different vegetations structure in the Paraná River Delta in Argentina.
The approach followed is based on the analysis of a temporal set of ENVISAT ASAR data which includes images acquired under different polarizations and incidence angles as well as different environmental conditions (water level, precipitation, and vegetation condition). Two marsh species, named *Junco* and *Cortadera,* were monitored. The comprehension of the observed backscattering features was addressed through electromagnetic models developed for these ecosystems. Results are validated with water level evaluations at specific points. A map showing estimated water levels below *Junco* and *Cortadera* areas, is presented.

1. INTRODUCTION

Areas near rivers, or in low-lying coastal places, are in risk of floods. Periods of heavy rain, not necessarily in the area, can lead to rises in the water level of streams and rivers to a point where main channels can no longer hold the volume of water. In wetland areas, it is claimed that this excess of water can be taken by marshes located in the floodplain separated of the mainstream channel by island levees. These marshes are continuously exchanging water with the mainstream channel, but in extreme flood conditions, when the river overflows, the net flux goes into the marsh direction [1]. When the river water level returns to normality, this excess of water is slowly returned to the mainstream channel. This capability is usually called "marsh buffer effect" because its effect is analogous to a low pass filter that "shapes" the mainstream flux.

In the Lower Delta of the Paraná River in Argentina, marshes are the most extended autochthonous vegetation. Two main species dominate the marsh vegetation: *Junco* and *Cortadera*, and together cover up to 45% of the wetland area (~ 800 Km^2). These marshes are mainly located in islands along the channels and are responsible for the water buffer effect on this wetland.

One important reason to extract information from this area is that the Paraná River watershed is quite large (3 million km^2 including upper Paraná and Paraguay River) and there is a large amount of people that interacts in some way with the water of this environment (more than 100 million in the whole basin).

In order to fully understand the type of marsh buffer effect present in the lower delta of the Paraná River, it is important to measure and monitor the water volume inside the wetland. Recent results address the use of Envisat ASAR observations for water level and water storage estimation in wetland marshes of the Paraná River Delta in Argentina [2]. This paper describes how ASAR observations and electromagnetic models were used to obtain estimates of water level below two marshes of different vegetations structure.

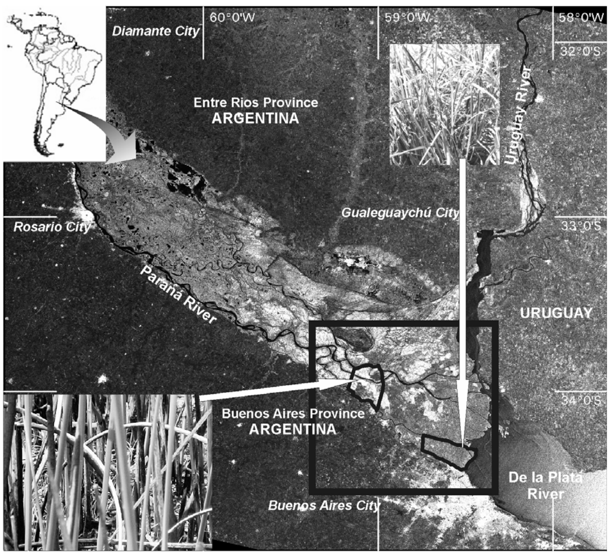

Figure1: Paraná River Delta study area.

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2. STUDY AREA

The Lower Paraná River Delta region stretches through the final 150 km of the Paraná basin. It covers approximately 2700 km^2, close to Buenos Aires city in Argentina (Fig. 1).

The landscape patterns of this region are subordinated to a flooding regime characterized by different sources of water, that is, local precipitation, and large rivers (Paraná River and De La Plata River) whose specific flooding patterns affect particular areas. Sometimes these sources add together provoking large flooding events.

The combination of local topographic gradients and a regional flooding regime constitutes the primary factor that determines the emergent natural vegetation, consisting of marshes growing in lowlands where the substrate is saturated or flooded either during long periods or permanently [3]. Conversely, forests are restricted to levees and other areas where soils are generally dry or flooded only during wind tides and (or) fluvial floods.

Fig. 1 shows an Envisat ASAR Wide Swath mode image (HH polarization) of the Paraná River Delta (study area is marked in black). It is possible to identify different structures through the different radar responses. Inside the study area, there are two easy differentiable structures: forests and Cortadera marshes with intermediate backscattering coefficients and Junco marshes, with their characteristic strong backscattering at HH polarization (see [4] for experimental results and [5] for an interaction model interpretation).

3. SAR OBSERVATIONS AND FIELD WORK

This study uses Envisat ASAR precision image products in Alternating Polarization mode (APP). Each image can be acquired under different incidence angles. Envisat-ASAR APP images have a nominal *equivalent number of looks* equal to 1.8 looks. Table 1 lists the 13 ASAR images that were processed and analyzed for this work. In addition, several RADARSAT 1 and ERS-2 images were also acquired and used in previous works [6], [7].

With the objective of describing and simulating *Junco* and *Cortadera* marsh radar signatures, for several flood conditions, incidence angles, and polarizations, in 2004 we started to use a detailed field work methodology simultaneously with Envisat data acquisitions. A rigorous and systematic characterization of the target made it possible to analyze the statistical distribution of target parameters [2] [8].

Mode	Polarization	Date	Season
S1	**VV/HH**	16/10/2003	Spring
S1	**VV/HH**	20/11/2003	Spring
S1	**VV/HH**	04/03/2004	Summer
S1	**VV/HH**	08/04/2004	Autumn
S1	**VV/HH**	13/05/2004	Autumn
S1	**VV/HH**	09/12/2004	Spring
S1	**VV/HH**	13/01/2005	Summer
S2	**HV/HH**	06/12/2003	Spring
S2	**HV/HH**	20/03/2004	Summer
S2	**HV/HH**	24/04/2004	Autumn
S3	**VV/HH**	01/03/2004	Summer
S3	**VV/HH**	05/04/2004	Autumn
S3	**VV/HH**	10/05/2004	Autumn

Table 1. Envisat ASAR images used in this paper.

4. FORWARD MODELS FOR MARSHES

Marsh backscattering coefficient (σ^0) is known to be related to several environmental variables [5]. Among the most important, are the marsh structural variables (plant geometry), marsh electrical variables (relative permittivity) and environmental conditions, like water level and wind direction and strength. Since most marshes are fixed to the wetland soil, it is expected that a change in water level is related to a change in emerged biomass. From experimental results, it is known that for both VV and HH polarizations:

1 – In the absence of flooding events, marsh σ^0 is relatively constant or is a known function of season.
2 – When water level increases, marsh σ^0 increases to a maximum that depends on marsh environmental variables.
3 – When water level overpass this maximum, marsh σ^0 decreases.
4 – When water level overpass the marsh height, marsh σ^0 decreases dramatically.

Since marsh σ^0 is a function of many variables, it is not easy to relate a change of σ^0 to a change in water level, since many environmental variables are known to change simultaneously [7]. A rational and commonly adopted method to estimate the dependency of σ^0 with water level changes is to model the interactions between the radar wave and the environment. To this aim, the scattering processes have been simulated by the electromagnetic model developed at Tor Vergata University [9]. In its general version, the model describes the soil as a homogeneous half space with a rough interface and the vegetation as a discrete ensemble of lossy dielectric elements. Canonical shapes, such as discs and cylinders, are selected for the elements. Details are given in [9]. Figure 2 and Figure 3 show the input architecture model for *Junco* and *Cortadera* respectively. The architecture model defines the main geometrical variables of the corresponding canonical bodies and their orientations.

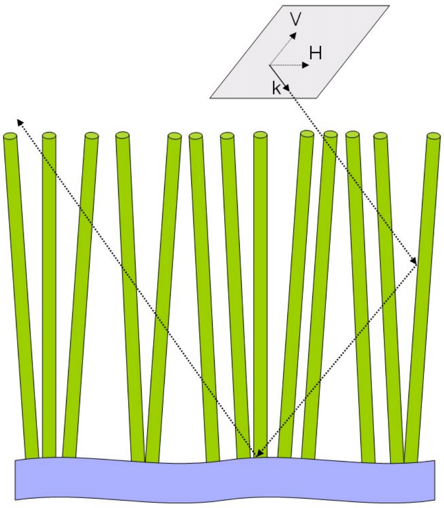

Figure 2: Architecture model of Junco marsh. This model defines the input variables of the interaction model. These are: Junco height, Junco plant density, Junco radius, Junco gravimetric moisture content, Junco dry matter density and Junco tilt angular distribution.

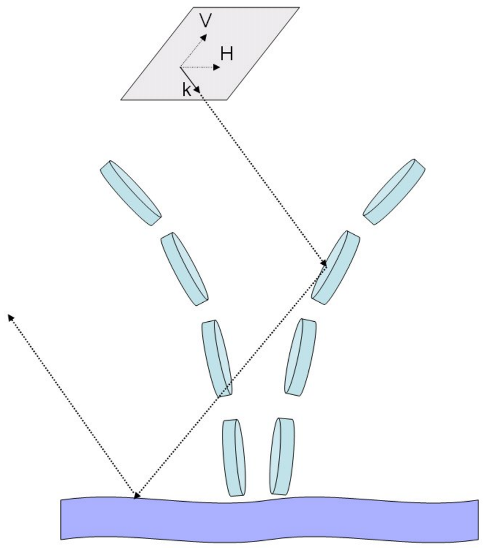

Figure 3: Architecture model of Cortadera marsh. This model defines the input variables of the interaction model. These are: Cortadera LAI, leaf density, leaf radius, leaf width, leaf moisture content, leaf dry matter density and leaf tilt angular distribution.

In [5] and [8], it is shown a comparison between the simulated and observed values of marsh σ^0 for different seasons and environmental conditions. It is also shown that there is a good agreement between simulated and observed σ^0 values.

5. STRATEGIES TO EXPLOIT THE POTENTIAL OF OBSERVATIONS AND MODELS

To correctly simulate the marsh σ^0 corresponding to a flooding event, we need to specify how a change in water level affects the observed σ^0. For both marshes, our hypothesis is that observed changes in σ° are related to a reduction in the emerged biomass caused by the flood [5].

The hypotheses for *Cortadera* are:

- the vertical leave density can be considered as uniform,
- the *Cortadera* leaves angular distribution is constant inside the marsh patch,
- the non-flooded (maximum) *Cortadera* LAI (*LAIMax*) is constant,

Then, we can establish a relationship between water level *x* and *LAI* such as:

$$x = \left(1 - \frac{LAI}{LAI_{Max}}\right) h_c \qquad (1)$$

where *x* is the water level, *LAI* is the emerged leaf area index, *LAImax* is the LAI when no water is present and *hc* is the *Cortadera* height. In this way, a change in emerged LAI can be related to a change in water laver.

The hypotheses for *Junco* are:

- the *Junco shoot* density is uniform,
- the *Junco shoot* angular distribution is constant inside the marsh patch,
- the non-flooded (maximum) *shoot* height is constant.

The water level inside the Junco patch can be expressed as:

$$x = h_{Max} - h_j \qquad (2)$$

where *x* is the water level , *hmax* is *Junco* shoot height when water no water is present and *hj* is the emerged *Junco* height.

For ENVISAT-ASAR S1-S3, HH, VV observations, an estimate of water level in *Junco* sites has been obtained with the aid of model simulations. First, we have simulated the σ^0 at VV and HH polarizations for all water level (*WL*) values between 1 and 180 cm (using 1 cm steps), for all the environmental condition of the acquired scenes. Then we have selected as "estimated water level" the *WL* value minimizing the Cost Function given by

$$CF = \sum_{m=1}^{Ms} \sum_{p=1}^{2} \left[\sigma^0_{ppS}(WL) - \sigma^0_{ppEm} \right]^2 \qquad (3)$$

where σ^0_{ppS} (WL) is the simulated backscattering coefficient at *pp* polarization for *WL* water level, σ^0_{ppEm} is the backscattering coefficient at the same polarization collected by ASAR over the marsh field and *Ms* is the number of marsh fields within the site. In this way, this algorithm chooses the *WL* that performs the best fit of HH and VV simultaneously [5].

6. RESULTS

Combining observations and models, the capacity of the ENVISAT ASAR instrument to estimate differences in water level within these marshes is used to generate a map of the marsh area showing the spatial distribution of water levels below the vegetation. Figure 4 and Figure 5 show the estimated water levels for different marsh patches of *Junco* and *Cortadera* respectively.

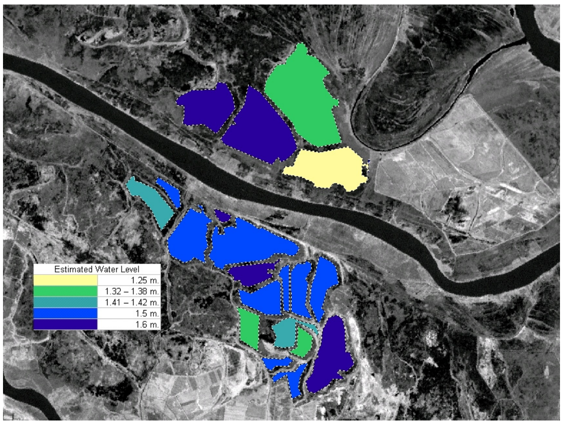

Figure 4: Estimated water level of different Junco patches

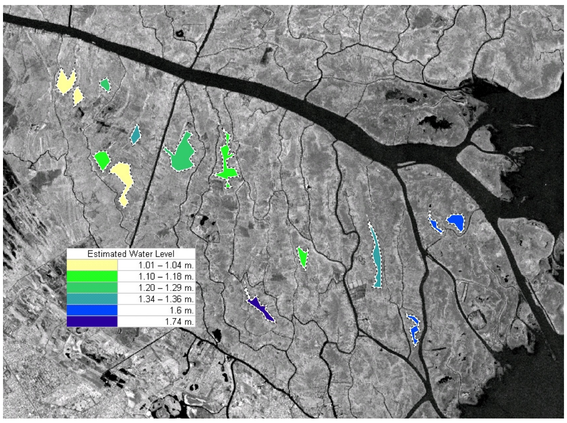

Figure 5: Estimated water level of different Cortadera patches

The approach proposed in this paper is able to estimate water level inside *Junco* and *Cortadera* marshes with an overall *rms* error of **22 cm** [5].

Since with ENVISAT ASAR we only observed one major flooding event, the retrieval scheme derived here is only valid for **water level ranges** between **5 cm and 1.8 meters.** For lower water levels, the soil is saturated but not flooded, the double bounce interaction mechanism present in the marshes is not significant and the retrieval algorithm is invalid. For higher water levels, the marshes are completely flooded (underwater) and the observed σ^0 is due to surface scattering in the water [2].

Once the water level within the marsh patches is determined, it is possible to estimate the water storage capacity by stating:

$$V = \int_A \int_x x \, dA \, dx \qquad (4)$$

where V is the water volume inside the marsh patch, A the area of the marsh patch and x the water level at every pixel. The first integral is easy to evaluate from the spatial profile of the marsh patch, but to evaluate the second one, is mandatory to use some information about the island bathymetry profile. As a first approximation,

$$V \cong A h \qquad (5)$$

where h is the mean water level inside the island patch. A volume error can be estimated considering the error in water level along with any uncertainties in the area determination and islands bathymetry profile. Considering all the error contributions, as an overall conservative assessment, this method can estimate marsh water storage capacity in areas near places were fieldwork has been done with a **55%** error [2]**.**

6. CONCLUSIONS

Radar observations are currently the only tool to monitor fluctuations in water level in marshes at a regional scale [10]. Interaction models constitute an excellent mean for understanding and simulating interactions mechanisms taken place in herbaceous marshes with different soil conditions (slightly flooded, partially flooded, completely flooded). Although the estimations of water level and water storage capacity obtained have large errors, these values are not only valid options, but up to now, the only ones to be used as inputs to hydrological models at basin scales.

For operating purposes, there is still a need for additional data to test how forward and inverse models work under different environmental conditions and in this way be able to detect model weaknesses and bugs to be able to refine them.

Our current activities dealing with improving the forward models include: to simulate HV with better accuracy, to use recent detailed measurements of vegetation moisture, to span a wider range of frequencies (from L to X bands), to make modifications to work with fully polarimetric data.

7. REFERENCES

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