SATELLITE ESTIMATION OF FLOODED AREA AND RIVER WATER LEVEL DYNAMICS

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ABSTRACT

The objective of this paper is to analyze the dynamics of flooded area and water level in a floodplain wetland. To this end we studied a flood that occurred in 2009-2010 related to an ENSO (El Niño/Southern Oscillation) event over the Paraná River delta. The method for obtaining flooded area fraction (f_f) and floodplain water level (WL), which is an extension of previously developed algorithms based on passive data, exploits the synergy of passive and active microwave signatures and model simulations of vegetation emissivity. The results are compared with, and plotted against, water level from Rosario port gauge and water level of a lagoon inside the floodplain obtained by microwave altimetry. This graphs are analyzed in terms of the possible equivalent topography of the floodplain.

Index Terms— Flooded area, water level, microwave remote sensing, Paraná River delta, equivalent topography

1. INTRODUCTION

Flooding is a major concern in the Plata Basin. This is due to the fact that the Paraná River has a long and wide floodplain, which has been settled and cultivated. Losses due to floods in Argentina during the 1983, 1992, 1998, 2007 and 2009-2010 floodings exceeded US$1 billion each. Therefore, providing information about the current state of the basin hydrologic condition in a systematic way is critical to the regional economies and society. In particular, it is of extreme importance to monitoring basin floodplain wetlands flood-drought cycles. These ecosystems extend along the Paraná-Paraguay axis and have highly dynamic exchanges of water with the river, presenting important annual and interannual variations. In this context, both floodplain water level and flooded area become relevant proxies of the flood condition and the total volume of water inside the floodplain. Moreover, the dynamics of these variables will be a raw indicator of floodplain overall hydrological behavior. Therefore, estimating these variables in a systematic way using remote sensing data, it is possible to constrain the outputs of hydrological forecast models. In this paper, a methodology to retrieve flooded area and water level in herbaceous wetlands, based on active/passive microwave data and an emission model [1],[2],[3],[4] is presented. We compare our results with microwave altimetry data [5], and analyzed floodplain behavior by studying the relationship between the fraction of flooded area (f_f) and floodplain water level (WL), Paraná River hydrometric level and water level for a lagoon inside the floodplain derived from altimetry data.

2. METHODOLOGY

2.1. Study Area

The Paraná River Delta, located at the final 300 Km of the La Plata Basin, is covered by a highly heterogeneous wetland, dominated by lagoons and different communities of herbaceous vegetation in the extended lowlands (Fig. 1). This area is subject to strong variations of water level, related to local rain and the contribution of up-water of Paraná and Paraguay rivers.

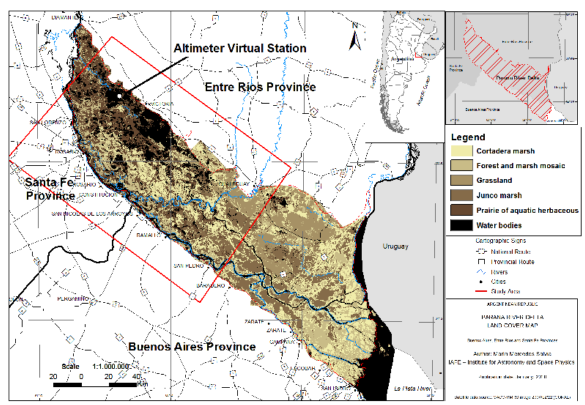

Figure 1. Paraná River Delta.

2.2. Flooding Event & Available data

In this work we analyze the flooding event that occurred in 2009-2010, related to an ENSO (El Niño/Southern Oscillation) phenomena. In this event, Paraná River water level rose above the levee level, flooding an extensive part of Paraná River Delta (Fig. 2). To estimate the hydrological condition of this area, we used both active and passive microwave signatures, as well as altimeter data and ancillary data. Details are given in Table 1.

Table 1. Available data

Sensor	Data used	Dates	Variable obtained
AMSR-E (C, X Bands)	L1B Tb	2009/01-2010/09	$PI = \frac{2*(Tb_V - Tb_H)}{(Tb_V + Tb_H)}$
ENVISAT ASAR (C Band)	WSM HH σ^0	2009/08-2010/09	Flooded area maps
ENVISAT altimeter Virtual Stations [5]	134-05 579-04	2009/01-2010/10 (monthly)	Water level
Emission model	Tor Vergata model [4]		
Auxiliary data	Daily water level in Rosario Port, Land cover map [7]		

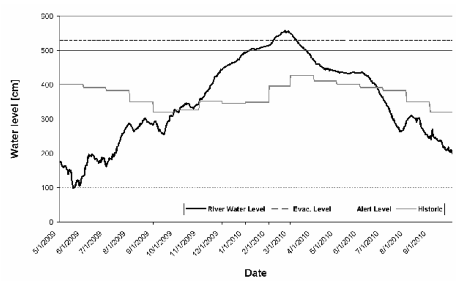

Figure 2. Water level in Rosario Port station during the 2009-2010 ENSO event.

2.3. Estimation of fraction of flooded area and water level inside the floodplain.

The general approach is based on the exploitation of the PI from a complete series of passive data, and the use of high resolution flooding maps based on SAR data in specific dates for parameter calibration [3]. The model has three end-members, that represent the contributions of water, non-flooded land, and inundated floodplain to the total observed polarization index PI_{obs}:

$$PI_{obs} = f_w PI_w + f_{nf} PI_{nf} + f_f PI_f \quad (1)$$

and

$$1 = f_w + f_{nf} + f_f \quad (2)$$

where PI_{obs} is the observed PI, f_w, f_{nf} and f_f are the fractional areas, and PI_w, PI_{nf}, and PI_f are the PI values of open water (rivers and lakes without emergent vegetation), non-flooded land, and seasonally flooded land, respectively. Algorithm main characteristics and hypothesis are detailed in [3].

2.4. Comparison with altimetry water level data.

In order to get some insight on the validity our estimations of flooded area fraction and water level, we compared this data with the water level estimations from two virtual stations obtained from LEGOS (Laboratoire d'Etudes en Géophisique et Oceanographie Spatiales) GOSH team (Geodesy, Oceanography et Hydrologie from Space) [6].

2.5. Analysis of fraction of flooded area vs. water level dynamics

One possible approach for the study of flooding dynamics is the analysis of the existent relation between water level (in a river and inside the floodplain) and flooded area in the floodplain. Thus, the characteristics of this relation are indicative of the equivalent hydrodynamic behavior of an area of the basin. This hydrodynamic behavior describes globally the water movements during flooding events (Fig. 3). We constructed graphs equivalent to Fig 3 for our study area comparing the following:

1) flooded area fraction obtained by SAR images vs. hydrometric river water level in Rosario (water level in the main river and main input of water into the system, Fig. 5).
2) flooded area fraction obtained by SAR images vs. water level for the two closest virtual stations from Hydroweb project [5],[6] (water level inside floodplain, Fig. 6).
3) flooded area fraction from SAR vs. floodplain water level obtained by AMSRE and emission model [4] simulations (mean water level inside floodplain, Fig. 7).

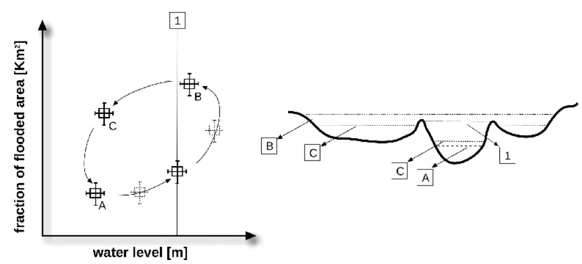

Figure 3. Schematic of the expected results for the relation flooded area fraction/ hydrometric water level. Left: flooded area fraction vs. hydrometric water level. Right: Equivalent topography schematic resulting from the graph on the left.

3. RESULTS & DISCUSION

Fig. 4 shows that water level measured on the floodplain by the altimeter and the hydrometric water level in the Rosario port have similar trends, even though altimeter data are monthly and Rosario are daily and the measuring point are different. Observed PI data are noisy, but increases with the flooding event, showing the already known fact that AMSRE PI are sensitivity to hydrological changes in the floodplain. Flooded area fraction from SAR images, however, shows a different trend, maintaining high values of ff even after the river and altimeter water level have descended. This demonstrates the buffer effect of wetlands, where the floodplain acts as a sponge taking in water more rapidly, though slower than the water level increase, and releasing it slowly after the river level has descended.

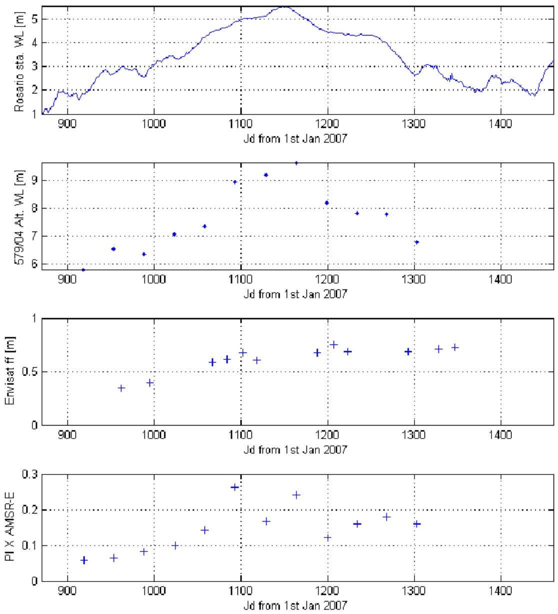

Figure 4. Top to bottom: water level from altimeter, hydrometrical water level in Rosario port, flooded area fraction from SAR images and observed PI from AMSRE (at X band).

Fig. 5 shows a scatter plot between flooded area fraction obtained from SAR data and hydrometric water level at Rosario port. We can see there are two main phases of the flooding event; in the first one, at the beginning of the event, both water level in Rosario port and flooded area fraction increase; in the second phase, water level decreases but flooded area fraction stays constant and high. The specific "hysteresis" shown for this event is related to the "buffer effect" of this wetland.

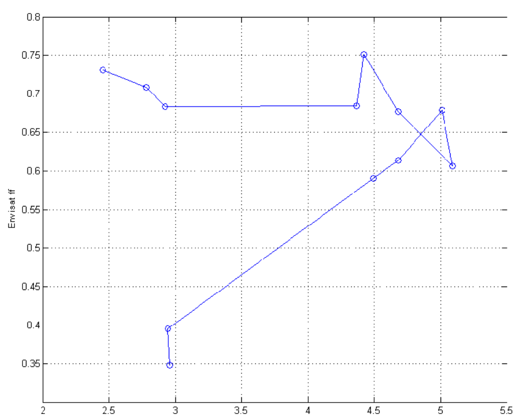

Figure 5. Flooded area fraction from SAR data vs. hydrometric river water level in Rosario port. To be compared with the scheme presented in Fig. 2.

Fig. 6 shows the relation between flooded area fraction obtained from SAR data and water level in an altimeter virtual station. The general trend is the same that the one in fig. 5, with some minor differences in the intensity of the changes.

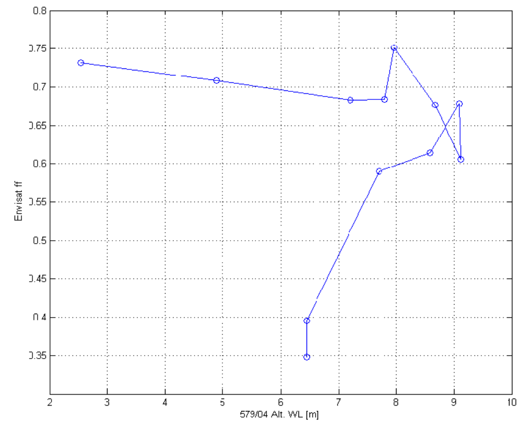

Figure 6. Flooded area fraction from SAR data vs. altimeter derived water level. To be compared with the scheme presented in Fig. 2.

Fig. 7 shows the relation between flooded area fraction obtained from SAR data and water level inside the floodplain, obtained using SAR and AMSRE data and emission model results [3]. In this case, there are three phases; the first two are similar to the ones in fig. 5 and 6, but the third phase shows a new increase of water level, with flooded fraction staying high, even with a little decrease.

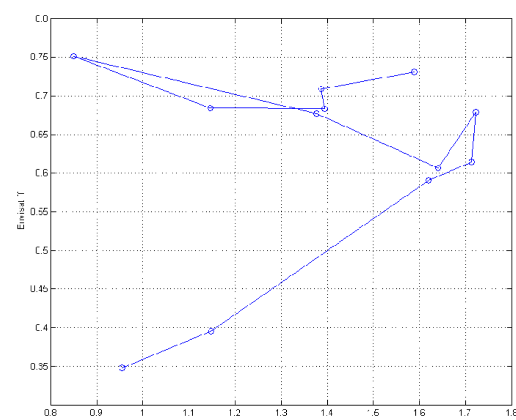

Figure 7. Flooded area fraction from SAR data vs. water level estimated using SAR and AMSRE data. To be compared with the scheme presented in Fig. 2.

Fig 5, 6 and 7 all show a part of the flooding dynamics of the Paraná River delta, but the information we can get from them is different, given the different sources of water level data. In the first two, water level is measured at a single point, inside water bodies, a large river South-West of the study area, and a large lagoon located in the NE portion of the area respectively. In the third one, the estimated water level is an integration of what is happening inside the whole study area (the integration given by the low resolution of the passive measurement), and therefore the estimated water level in an "equivalent mean water level".

The fact that the dynamics shown in fig 5 and 6 are so similar, being the lagoon all the way across the floodplain from Rosario port, is an indication that the source of flooding of this lagoon may be another part of Paraná River, up-waters from Rosario.

The fact that fig. 7 shows such a different dynamics from the ones in figs. 5 and 6 could be implying that the changes in the water level of water bodies is not such a good proxy for what is going on in the floodplain, even when the water body is inside the floodplain. The complexity of the relation between flooded fraction and water level shown in fig. 7 makes the estimation of an equivalent topography schematic not trivial. One thing we can say is that the floodplain does not behave like a homogeneous "container", but has at least two or more parts with internal barriers.

In summary, the approach used on this work allows for the analysis of current hydrological condition in terms of the flooded area vs water level space, and the posing of different possible future flooding scenarios, which would be useful for flooding forecast and alert.

4. ACKNOWLEDGEMENT

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